National Lakes Assessment

A Collaborative Survey of the Nation's Lakes

U.S. Environmental Protection Agency (USEPA). 2009. *National Lakes Assessment*: *A Collaborative Survey of the Nation's Lakes.* EPA 841-R-09-001. U.S. Environmental Protection Agency, Office of Water and Office of Research and Development, Washington, D.C.

Cover photo of Emerald Bay on Lake Tahoe courtesy of ©Ted C. McRae http://beetlesinthebush.wordpress.com

Acknowledgements

The EPA Office of Water (OW) and Office of Research and Development (ORD) would like to thank the many people who contributed to this project. Without the collaborative efforts and support by state and tribal environmental agencies, federal agencies, universities and other organizations, this groundbreaking assessment of lakes would not have been possible. In addition, the survey could not have been done without the dedicated help and support of enumerable field biologists, taxonomists, statisticians and data analysts, as well as program administrators, regional coordinators, project managers, quality control officers, and reviewers. To the many participants, EPA expresses its gratitude.

Collaborators

Alabama Department of Environmental Management
Arizona Department of Environmental Quality
Blackfeet Tribe, Environmental Program
California Department of Fish and Game
California State Water Resources Control Board
Pueblo de Cochiti Department of Natural Resources and Conservation
Colorado Department of Public Health and the Environment
Connecticut Department of Environmental Protection
Delaware Department of Natural Resources
Eastern Shoshone Tribe and Northern Arapaho Tribe, Environmental Program
Florida Department of Environmental Protection
Georgia Department of Natural Resources
Idaho Department of Environmental Quality
Illinois Environmental Protection Agency
Indiana Department of Environmental Management
Iowa Department of Natural Resources
Lac Courte Oreilles Band of Lake Superior Chippewa, Conservation Department
Lac du Flambeau Band of Lake Superior Chippewa, Tribal Natural Resources Department
Leech Lake Band of Ojibwe, Division of Resource Management
Maine Department of Environmental Protection
Maryland Department of Natural Resources
Massachusetts Department of Environmental Protection
Michigan Department of Environmental Quality
Minnesota Pollution Control Agency
Mississippi Department of Environmental Quality
Montana Department of Environmental Quality
Nevada Division of Environmental Protection
New Hampshire Department of Environmental Services
New Jersey Department of Environmental Protection
New York State Department of Environmental Conservation
North Dakota Department of Health
Ohio Environmental Protection Agency
Oklahoma Water Resources Board
Oregon Department of Environmental Quality
Pennsylvania Department of Environmental Protection
Pyramid Lake Paiute Tribe
Rhode Island Department of Environmental Management

Sisseton-Wahpeton Sioux Tribe, Environmental Program
South Dakota Department of Environment and Natural Resources
Spirit Lake Nation, Tribal Environmental Administration
Tennessee Department of Environment and Conservation
Texas Commission of Environmental Quality
Turtle Mountain Band of the Chippewa Indians Environmental Program
Utah Division of Environmental Quality
Vermont Department of Environmental Conservation
Virginia Department of Environmental Quality
Washington Department of Ecology
West Virginia Department of Environmental Protection
White Earth Band of Chippewa, Natural Resources Department
Wisconsin Department of Natural Resources

The following people played a pivotal role and lent their expertise to the data analysis of this project. These individuals painstakingly reviewed the dataset to ensure quality and consistency. These NLA analysts included Neil Kamman (lead, on detail from VT Department of Environmental Conservation), Richard Mitchell, and Ellen Tarquinio from EPA Office of Water; Phil Kaufmann, Tony Olsen, Dave Peck, Spence Peterson, Steve Paulsen, Amina Pollard, John Stoddard, John Van Sickle and Henry Walker from EPA Office of Research and Development; Donald Charles and Mihaele Enache from the Academy of Natural Sciences, Philadelphia PA; Charles Hawkins from Utah State University; Alan Herlihy from Oregon State University; Paul Garrison from WI Department of Natural Resources; Jennifer Graham and Keith Loftin from U.S. Geological Survey, Lawrence, KS; Jan Stevenson from Michigan State University, and Julie Wolin from Cleveland State University, OH.

Contributors

EPA would also like to thank those people who lent their scientific knowledge and/or writing talent to this report.

Steve Heiskary, Minnesota Pollution Control Agency, MN; Neil Kamman, Department of Environmental Conservation, VT; Terri Lomax, Department of Environmental Conservation, AK; Alice Mayio, EPA Office of Wetlands, Oceans and Watershed, Washington, DC: Amy Smagula, Department of Environmental Services, NH; Kellie Merrell, Department of Environmental Conservation, VT; Leanne Stahl, EPA Office of Science and Technology, Washington, DC.

The National Lakes Assessment survey project was led by Susan Holdsworth (OW) and Steve Paulsen (ORD) with significant programmatic help from Sarah Lehmann, Alice Mayio, Richard Mitchell, Dan Olsen, Carol Peterson, Ellen Tarquinio, Anne Weinberg, and EPA Regional Monitoring Coordinators. Contractor support was provided by Computer Sciences Corp., Dynamac Corp., EcoAnalysts, Inc., Great Lakes Environmental Center, Inc., Raytheon Information Services, TechLaw, Inc. and Tetra Tech, Inc.

Additional Reports and Information

To augment the findings of this report, EPA is providing several additional reports. The first is the *National Lakes Assessment: Technical Appendix.* This appendix describes in detail the data analyses and scientific underpinnings of the results. It is intended to aid States and other institutions who would like a more in-depth explanation of the data analysis phase with the possible intention of replicating the survey at a smaller scale. Additional results are also forthcoming. Due to a number of reasons, EPA is not able to report at this time the results from several indicators (*e.g.*, sediment mercury, *enterococci*, and benthic macroinvertebrates). Work is on-going for each of these indicators and results will be published when complete. The Technical Appendix, Field Methods and Laboratory Protocols are currently available on EPA's web site at http://www.epa.gov/lakessurvey/.

For those wishing to access data from the survey to perform their own analyses, EPA has made flat files of the data available via the internet at http://www.epa.gov/owow/lakes/lakessurvey/web_data.html. Additionally, raw data and information on the sampled lakes will be uploaded to EPA's STOrage and RETrieval (STORET) warehouse at http://www.epa.gov/STORET.

Table of Contents

Tables and Figures

Photo courtesy of Frank Borsuk

Executive Summary

"A lake is the landscape's most beautiful and expressive feature. It is earth's eye; looking into which the beholder measures the depth of his own nature."

These words by the American poet Henry David Thoreau underscore America's love of lakes. Lakes are places of reflection, relaxation, and repose, but like all our waters, they are being increasingly stressed. Growing anthropogenic pressures have prompted many governments, associations, and individuals to invest time in preserving or restoring the water quality of their lakes. To protect our nation's lakes, Americans must strive to understand how their actions as individuals and as a society are affecting them.

Under the Clean Water Act (CWA), the U.S. Environmental Protection Agency (EPA) must report periodically on the condition of the nation's water resources by summarizing water quality information provided by the states. However, approaches to collecting and evaluating data vary from state to state, making it difficult to compare the information across states, on a nationwide basis, or over time. EPA and the states are continually working on ways to address this problem to improve water quality reporting.

Congress, environmental groups, and concerned citizens routinely ask EPA questions about the quality of the nation's waters such as: What are the key problems in our waters? How widespread are the problems? Are there hotspots? Are we investing in water resource restoration and protection wisely? Are our waters getting cleaner? To better answer questions about the condition of waters across the country, EPA along with its state and tribal partners have embarked on a series of surveys to be conducted under the National Aquatic Resource Surveys (NARS) program. This relatively new program provides statistically valid data and information vital to describing water resource quality conditions across the country, how these conditions vary with geographic setting, and the extent of human and natural influences.

The National Lakes Assessment (NLA) is one in a series of annual NARS surveys. The NLA is the first statistical survey of the condition of our nation's lakes, ponds, and reservoirs.[1] Based on the sampling of over 1,000 lakes across the country, the survey results represent the state of nearly 50,000 natural and man-made lakes that are greater than 10 acres in area and over one meter deep. In the summer of 2007, lakes were sampled for their water quality, biological condition, habitat conditions, and recreational suitability. Field crews used the same methods at all lakes to ensure that results were nationally comparable. For many of the indicators, scientists analyzed the results against a reference condition. Reference conditions were derived from a set of lakes that were determined to be the least disturbed lakes for a region.

Key Findings

Biological Quality - 56% of the nation's lakes are in good biological condition. Natural lakes had a higher percentage of lakes in good condition than man-made lakes (Figure ES-1).

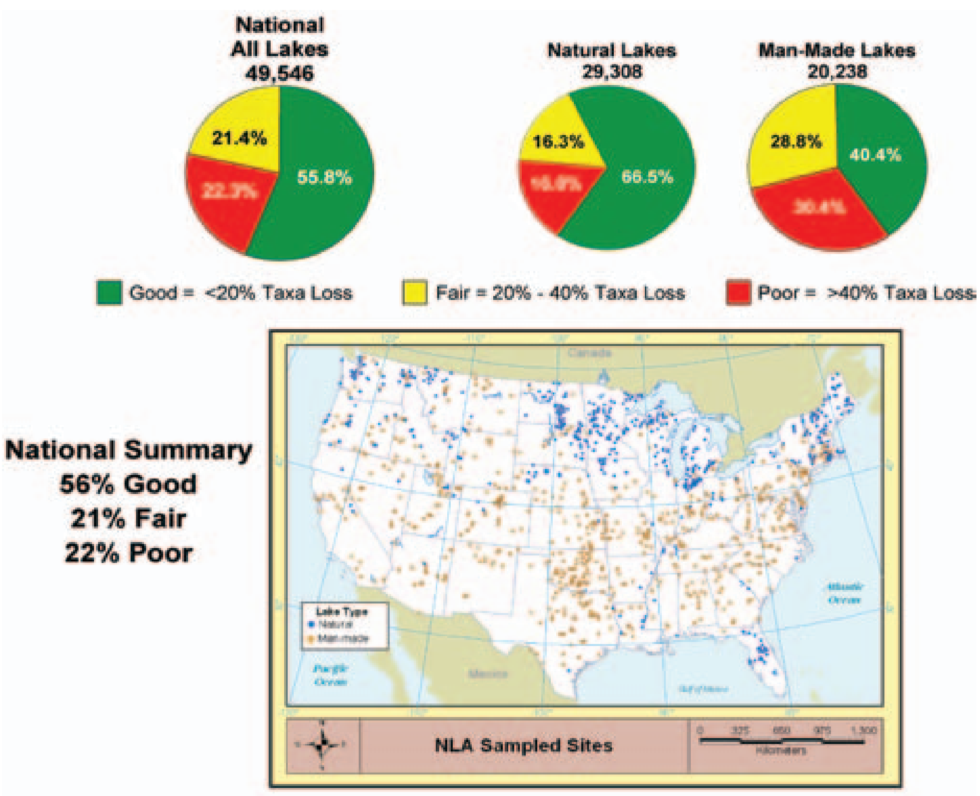


Figure ES-1. Biological condition of lakes nationally and based on lake origin.

[1]The full report including technical supporting documents is available on-line at http://www.epa.gov/lakessurvey/

Lake Physical Habitat - Of the stressors included in the NLA, poor lakeshore habitat is the biggest problem in the nation's lakes; over one-third exhibit poor shoreline habitat condition. Poor biological health is three times more likely in lakes with poor lakeshore habitat (Figure ES-2).

Nutrients - About 20% of lakes in the U.S. have high levels of phosphorus or nitrogen. High nutrient levels are the second biggest problem in lakes. Lakes with excess nutrients are two-and-a half-times more likely to have poor biological health (Figure ES-2).

Algal Toxins - The NLA conducted the first-ever national study of algal toxins in lakes. Microcystin – a toxin that can harm humans, pets, and wildlife – was found to be present in about one-third of lakes and at levels of concern in 1% of lakes.

Fish Tissue Contaminants - A parallel study of toxins in lake fish tissue shows that mercury concentrations in game fish exceed health based limits in about half of lakes (49%); polychlorinated biphenyls (PCBs) at potential levels of concern are found in 17% of the lakes.

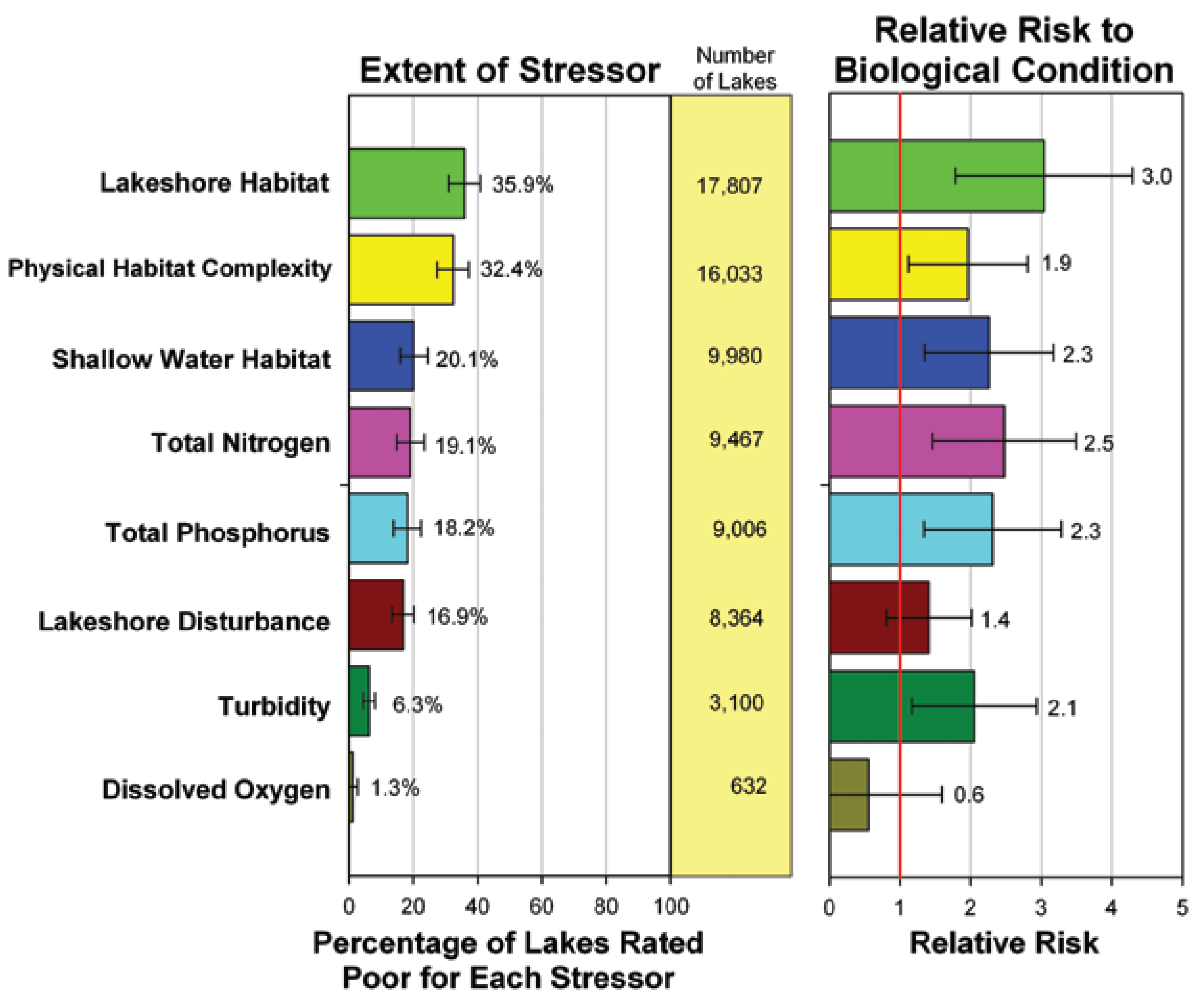


Figure ES-2. Extent of stressor and relative risk of stressor to biological condition.

Trophic Condition - The NLA establishes the first nationally consistent baseline of trophic status. Over 36% of the nation's lakes are mesotrophic, based on chlorophyll-*a* concentrations.

Changes in Trophic Condition - When compared to a subset of wastewater-impacted lakes sampled 35 years ago, trophic status improved in one-quarter (26%) and remained stable in over half (51%) of those lakes (Figure ES-3). This could indicate that, when considering rising populations in these areas, investments in wastewater pollution control are working.

Implications

As these results show, EPA and its state and tribal partners have begun to answer important national questions about the condition of the country's lakes. The results establish a national baseline status for future monitoring efforts which can be used to track scientifically credible trends in lake conditions. Successive surveys will help answer the question "Are our lakes getting better?"

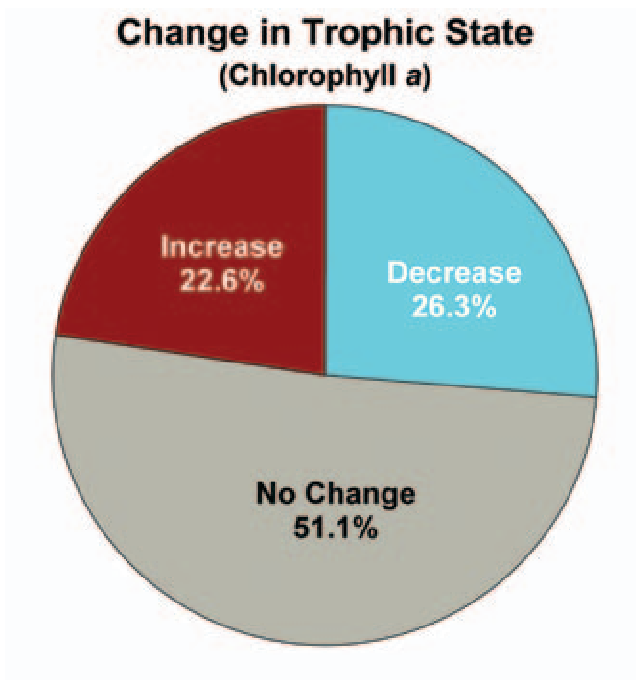


Figure ES-3. Proportion of National Eutrophication Survey (NES) lakes that exhibited improvement, degradation, or no change in trophic state based on the comparison of the 1972 National Eutrophication Survey and the 2007 National Lakes Assessment.

For water resource managers, policymakers, boaters, swimmers, and others, the NLA findings suggest:

- Poor lakeshore habitat condition imparts a significant stress on lakes and suggests the need for stronger management of shoreline development, especially as development pressures on lakes keep steadily growing.

- Effective nutrient management continues to be needed in the nation's lakes. Excess levels of nutrients contribute to algae bloom, weed growth, reduced water clarity, and other lake problems. The adverse impact of nutrients on aquatic life, drinking water, and recreation remains a concern.

- Local, state and national initiatives to protect the integrity of lakes should center on restoring the natural state of shoreline habitat – particularly vegetative cover and nutrient loading. Managers, residents, businesses, and community leaders should work together and enhance their efforts to preserve, protect, and restore their lakes and the natural environment surrounding them.

CHAPTER 1.
INTRODUCTION

Phelps Lake, Grand Teton National Park, WY. Photo courtesy of Great Lakes Environmental Center.

IN THIS CHAPTER

Chapter 1
Introduction

A Highly Valued and Valuable Resource

For anyone who went fishing as a child, water-skiing as a teen, or bird-watching as an adult, lakes are special places. Healthy lakes enhance the quality of life. In addition to supplying people with essential needs like drinking water, food, fiber, medicine, and energy, a lake's ecosystem is important in providing habitat for wildlife, recreation, aesthetics, reducing the frequency and severity of floods, shaping landscapes, and affecting local and regional climates. Lakes provide habitat for wildlife and enjoyment for people while supporting intrinsic ecological integrity for all living things.

It is difficult to put a price on a natural treasure. Certainly, from a vacationer's perspective, lakes are invaluable, providing endless enjoyment and relaxation year-round. According to the U.S. Fish and Wildlife Service, 30 million Americans went fishing in 2006 and $30 billion was spent on recreational fishing. Locally, this translates into important economic and recreational benefits. For example, Lake Champlain, on the border of Vermont and New York, has over 65 beaches and 98 fishing-related businesses. According to the 2003 Lake Champlain Management Plan, in 1998 a total of $3.8 billion was generated from tourism. As more and more people use lakes for their livelihood and recreation, the competition for lake resources will continue.

Protecting lake ecosystems is crucial not only to protecting this country's public and economic health, but also to preserving and restoring the natural environment for all aquatic and terrestrial living things. Lake protection and preservation can only be achieved by making informed lake management policy decisions at and across all jurisdictional levels.

Why a National Survey?

Water resource monitoring in the U.S. has been conducted by many different organizations over many decades using a variety of techniques. States and tribes conduct monitoring to support many Clean Water Act (CWA) programs. Section 305(b) of the CWA requires the U.S. Environmental Protection Agency (EPA) to report periodically on the condition of the nation's water resources by summarizing information provided by the states. Yet approaches to collecting and assessing data vary from state to state, making it difficult to compare the information across states or on a nationwide basis. Each of these monitoring efforts provides useful information relative to the goals of the individual programs, but integrating the data into a nationwide assessment has been difficult.

In recent years, a number of independent reports have identified the need for improved water quality monitoring and analysis at a national scale. Among these, the General Accounting Office (2000) reported that EPA and states cannot make statistically valid assessments of water quality and lack the data to support key management decisions. The National Research Council (2001) recommended that EPA and states promote a uniform, consistent approach to water monitoring and data collection to better support core water management programs. The National Academy of Public Administration, in its 2002 report entitled, *Understanding What States Need to Protect Water Quality*, concluded that improved water quality monitoring is necessary to help state agencies make better decisions and use limited resources more effectively. These reports underscore the need for more efficient and cost-effective ways to understand the magnitude and extent of water quality problems, the causes of these problems, and practical ways to address the problems.

State Water Quality Reports

Under section 305(b) of the Clean Water Act the states must submit biennial reports on the quality of their water resources. According to the most recently published National Water Quality Inventory Report (2004) the states assessed just over a third of the nation's waters — 37% or 14.8 million acres of the nation's 40.6 million acres of lakes, ponds and reservoirs. Of the lakes that were assessed, over half, 58% or 8.6 million acres, were identified as impaired or not supporting one or more of their designated uses such as fishing or swimming. The states cited nutrients, metals (such as mercury), sewage, sedimentation and nuisance species as the top causes of impairment. Leading known sources of impairment included agricultural activities and atmospheric deposition, although for many lakes, the sources of impairment remain unidentified.

The National Aquatic Resource Surveys

To bridge this information gap, EPA, other federal agencies, states and tribes are collaborating to provide the public with improved environmental information. Statistical surveys are one way of addressing water resource assessment needs. By choosing a statistical design with standardized field and laboratory protocols, the EPA, states and tribes are able to collect and analyze data that are nationally consistent and representative of waterbodies throughout the U.S. These statistical surveys offer a cost-effective and scientifically valid way to fulfill statutory requirements, complement traditional monitoring programs, and support a broader range of management decisions.

The surveys are designed to answer such questions as:

- What is the extent of waters that support a healthy biological condition, recreation, and fish consumption?
- How widespread are major stressors that impact water resource quality?
- Are we investing in water resource restoration and protection wisely?
- Are our waters getting cleaner?

The help of state partners was essential.
Photo courtesy of Frank Borsuk.

The specific goals of NARS are to generate scientifically valid information on the condition of water resources at national and ecoregional scales, establish baseline information for future trends assessment, and assist states and tribes in enhancing their water monitoring and assessment programs.

The focus of NARS is on waterbodies as groups or populations, rather than as individual waters. For example, a state or local manager may be interested in nutrient levels in a given lake over time. NARS, on the other hand, allows one to examine the percentage of the nation's lakes that have experienced changes in nutrient levels over time. Findings such as these help drive national water quality management decisions.

By generating population estimates of condition, the national statistical surveys and other statistical surveys have begun to provide answers to water resource questions with a known level of confidence. Working with its partners in states, tribes, territories, and other federal agencies, EPA has in recent years conducted statistical surveys of coastal waters, wadeable streams, and contaminants in lake fish tissue. The Agency's plans are to survey each of the five waterbody types, (lakes, rivers, streams, wetlands, and estuaries), on a 5-year rotating basis. EPA and its partners anticipate that the national surveys will continue to foster collaboration across jurisdictional boundaries, build state and tribal infrastructure and capacity for enhanced monitoring efforts, and achieve a robust set of statistically-sound data for better, more informed water resource quality management policies and decisions.

The National Lakes Assessment (NLA) is one component of the National Aquatic Resource Surveys. This report summarizes the first-ever assessment of lakes across the continental United States using consistent protocols and a modern, scientifically-defensible statistical survey approach.

Using the National Aquatic Resource Surveys

Because of their scientific credibility, results from these surveys are being used in other scientific contexts. Most notably is the recent Heinz Center Report, *The State of the Nation's Ecosystems, 2008*. The Heinz Center's report is designed to provide a high level, comprehensive and scientifically sound account on the state of the nation's ecosystems. The Heinz Center uses data derived from EPA's Wadeable Streams Assessment report and National Coastal Condition Report to answer a number of outstanding questions about surface water health in our country. Information from on-going and upcoming national surveys will help fill gaps identified for other water resources and show trends in national water quality.

HIGHLIGHT

Think Globally — Act Locally. Restoring Mousam Lake

"Every little bit helps" is perhaps the fundamental tenet of the estimated 3,000 to 4,000 local watershed groups across the country. Many communities are proving that they can make a noticeable difference in their neighborhood water resource. In York County, Maine, the Soil and Water Conservation District (SWCD) and the Mousam Lake Regional Association (MLRA) together with residents, townships, state agencies and others embarked on the Mousam Lake Water Quality Improvement Project. With widespread collaboration and some funding, they were able to clean up an impaired lake.

Confronting Environmental Challenges

Mousam Lake, a 863-acre lake located at the southern point of Maine, is a popular spot for boaters, anglers, and vacationers with its sandy shores and excellent cold and warm water trout fisheries. However, this 21- square mile watershed suffered from suburbanization and the conversion of forested land to driveways and parking lots. The lake's shoreline is heavily developed with over 700 seasonal and year-round homes and a heavily used boat ramp. For the past several decades, Mousam Lake has endured increased soil erosion and pollution from stormwater runoff from home construction, lawns and roads, and from failing septic systems. Higher levels of phosphorus have led to increased algal growth, decreased water clarity and lower levels of dissolved oxygen. In the 2003 Total Maximum Daily Load (TMDL) assessment, excess phosphorus was identified as the major impairment. This downward trend in water quality resulted in a steady decline in the lake's once viable ecology and that of its surrounding aquatic habitats. Maine's Department of Environmental Protection (MDEP) attributes the problem to soil erosion and polluted runoff from residential properties and camp roads and effluent from inadequate septic systems located in the sandy soils around the lake. The TMDL assessment estimated that to meet Maine water quality standards, the annual amount of phosphorus reaching the lake would need to be reduced by 27%.

A Decade of Effort

Since 1997, the York County SWDC, MLRA, MDEP, and the towns of Acton and Shapleigh have been working together to address sources of pollution in Mousam Lake and foster long-term watershed stewardship. In 1999, the Mousam Lake Water Quality Improvement Project began. With help from EPA, the Maine Department of Transportation and the Maine Department of Agriculture negotiated cost share agreements with public and private landowners, and best management practices were initiated at 45 priority sites. Technical assistance was provided to another 77 landowners. Projects included stabilizing shoreline erosion, improving gravel road surfaces and installing and/or upgrading roadside drainages. Twenty-one roads were repaired. In 2001, the Lake Youth Conservation Corps program was established to help with the implementation of best management practices, raise local awareness and commitment to lake protection, and involve local youth in environmental stewardship. Since 2007, the youth have completed over 115 projects and continue to repair an average of 18 sites each year with annual support from the towns of Acton and Shapleigh. The total cost for the project was $1.1 million with local townspeople and others contributing over $400,000 in matching funds or in-kind services.

A Cleaner, Healthier Lake

In 1998 MDEP designated Mousam Lake as impaired and added it to the state's section 303(d) list of waters not meeting water quality standards, a requirement of the federal Clean Water Act. From 1999 through 2006, a galvanized community tackled the problem and in 2007, monitoring results indicated that pollution loads in the lake were reduced by more than 150 tons/per year of sediment and 130 pounds/per year of phosphorus. Water clarity depth has increased by a full meter from what it was ten years ago. Today, erosion control projects continue, thus keeping an estimated 76 tons of sediment and 64 pounds of phosphorus out of the lake each year. In 2006, Mousam Lake was removed from the state's 303(d) list of impaired waters.

Staff and a small cadre of local leaders are continuing their campaign to keep the lake in good health. Community outreach and education activities are ongoing to inform residents on how they can help. As part of the project, numerous newsletters have gone to every household in the watershed; MLRA holds annual meetings; the SWCD conducts workshops and delivers presentations; 30 construction sites have been acknowledged with "Gold Star" signs for environmental stewardship; and more than 200 homeowners attended one of the thirteen "Septic Socials" to learn about septic system function, proper maintenance and water conservation.

Every Little Bit Helps

In many, many instances, small, local efforts can provide incentives and moral support for others. The success of the Mousam Lake project has inspired protection efforts on several neighboring lakes. The Acton Wakefield Watershed Alliance, the Square Pond Association, and the Loon Pond Association are now busy with their own restoration activities. For more information or tips from the people at Mousam Lake, contact Joe Anderson at York County SWCD at (207) 324-0888, janderson@yorkswcd.org or Wendy Garland (MDEP) at (207) 822-6320, wendy.garland@maine.gov.

Vegetated buffer planting by Master Gardeners.
Photo courtesy of Deborah Kendall.

CHAPTER 2.

DESIGN OF THE LAKES SURVEY

Photo courtesy of Washington Department of Ecology

IN THIS CHAPTER


Photo courtesy of Great Lakes Environmental Center

Chapter 2
Design of the Lakes Survey

Lakes in the U.S. are as varied and unique as the landscape surrounding them. Receding glaciers formed thousands of lakes in the northwestern, upper midwestern, and northeastern parts of the country. Glacial action formed the Finger Lakes in New York, the Adirondack region, the kettle ponds in New England, as well as numerous lakes and "prairie potholes" located in Minnesota, Wisconsin, Iowa, and the Dakotas. In contrast, Oregon's Crater Lake is a water-filled volcanic depression, as is Yellowstone Lake in Wyoming. Lake Tahoe in California and Pyramid Lake in Nevada were formed by tectonic action. Along major rivers, like the Mississippi, oxbow lakes were formed from meandering river channels. Similarly, damming of the Columbia River and the Colorado River has created large man-made lakes and reservoirs. Smaller previously impounded streams comprise thousands of man-made lakes that provided energy for mills during industrialization. Natural lakes are scarce across the southern U.S. Many of the lakes in the arid southwestern and the humid southeastern U.S. are man-made lakes or reservoirs. The NLA survey included examples of all of these lake types.

Areas Covered By the Survey

The NLA encompasses the lakes, ponds and reservoirs of the continental U.S. including private, state, tribal and federal land. Although not included in this report, a lake-sampling project is underway in Alaska. Hawaii was not included in the national survey design. Information from the NLA is also presented for both natural and man-made lakes to present any difference in biological condition or responses to stressors.

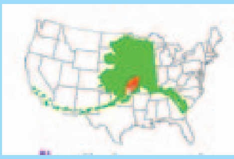
NLA results are reported for the continental U.S. and for 9 ecological regions (ecoregions). Areas are included in an ecoregion based on similar landform and climate characteristics (see Chapter 6 and Figure 20). Assessments were conducted at the ecoregion level because the patterns of response to stress are often best understood in a regional context. Some states participating in the NLA assessed lake condition at an even finer state-scale resolution than the ecoregional scale by sampling additional random sites within their state boundaries. Although these data are included in the analysis described in this report, state-scale results are not presented.

Selecting Lakes

Since a census of every lake in the country is cost prohibitive and beyond the reach of any program, EPA used a statistical sampling approach incorporating state-of-the-art survey design techniques. The first step, to ascertain the number of lakes in the country, was challenging because there is no comprehensive list or source for all lakes in the U.S. The best resource available is the USGS/EPA National Hydrography Dataset or NHD. The NHD is a multi-layered series of digital maps that reveal topography,

Alaska's Lake Assessment

By Terri Lomax, AK Department of Environmental Conservation



The State of Alaska is about one-fifth the land mass of the continental U.S. Most of it is sparsely populated with extremely limited access. This limited access has helped preserve its rugged beauty and abundant natural resources. But Alaska is facing pressure from climate change and natural resource development. In the populated areas, the main causes of waterbody pollution are urban runoff and agricultural activity.

There are an estimated 3 million lakes in Alaska. Instead of being a full participant in the National Lakes Survey, the State of Alaska opted to conduct a regional assessment. It focused on the Cook Inlet Basin, an area located in the southcentral part of the state; at 39,325 square miles, it is slightly smaller than the state of Kentucky. The State selected this area because the only agricultural activity of significance occurs within the Cook Inlet Basin.

Alaska's lake assessment began in 2007 with a pilot study of four lakes. This pilot study was focused on access and coordinating logistics of sampling, procedures, and analysis. In 2008, the full project was completed with sampling of 50 lakes in the Cook Inlet ecoregion. The field crew was from the Alaska Department of Environmental Conservation and the University of Alaska Anchorage Environment & Natural Institute. In addition to the National Lakes Assessment indicators, fish tissue for metals and mercury, sediment trace metals, and core dating were added to the study.

To date, all water chemistry, habitat, and lake profile data has been analyzed. Biological indicators, sediment metals and mercury, and fish tissue samples are currently being analyzed. All data collected must undergo quality assurance review before a final release of the data. However, initial results indicate that lakes in the Cook Inlet ecoregion of Alaska are healthy.

area, flow, location, and other attributes of the nation's surface waters. When queried, NHD has 389,005 features listed that could potentially be lakes, ranging in size from less than 2.4 acres (1 hectare) up to the largest lakes in the country. Figure 1 illustrates the sample framework for the survey.

Initial discussion by states and EPA regarding the scope of the survey focused on the size of lakes that were to be considered in the target population. It was agreed that, to be included, the site had to be a natural or man-made freshwater lake, pond or reservoir, greater than 10 acres (4 hectares), at least 3.3 feet (1 meter) deep, and with a minimum of a quarter acre (0.1 hectare) open water. The Great Lakes and the Great Salt Lake were not included in the survey, nor were commercial treatment and/or disposal ponds, brackish lakes, or ephemeral lakes. After applying the criteria, 68,223 waterbodies were considered lakes by the NLA definition and thus comprised the target population (Figure 1, 3rd bar).

Other factors in lake selection included accessibility. In some cases, crews were either denied permission by the landowner or unable to reach the lake for safety reasons, such as sharp cliffs or unstable ridges. Using data from the crews' experience and pre-sampling reconnaissance, it was estimated that 27% or 18,677 lakes fell into the inaccessible category. This left 49,546 lakes which could be assessed - inference

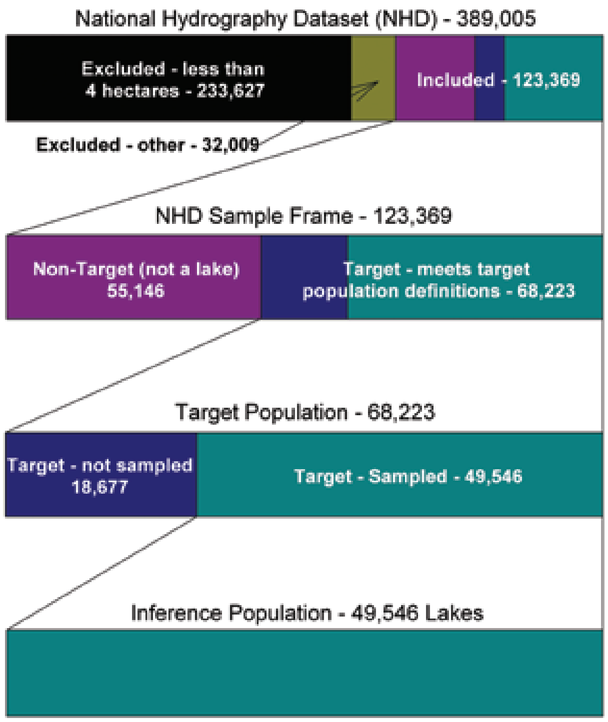


Figure 1. The process of lake selection. Starting with the NHD list of waterbodies, potential lakes are eliminated due to not meeting set criteria for inclusion in the survey (top bar), not being a lake (2nd bar), and inaccessibility (3rd bar) leaving the number of sampleable lakes or inference population (4th bar).

population (bottom bar). In the end, a total of 1,028 lakes were sampled in the survey. These 1,028 lakes represent the population. For quality assurance purposes, 10%, of the target lakes were randomly selected for a second sampling later in the summer.

Due to the selection process, the sampled NLA lakes represent 49,546 lakes or 73% of the target population. Thus, throughout this report, percentages reported for a given indicator are relative to the 49,546 lakes. For example, if the condition is described as poor for 10% of lakes nationally, this means that the number of lakes estimated to be poor for that indicator is 4,955 lakes.

As an added feature, the design specifically included some sites from EPA's 1972 National Lake Eutrophication Study (NES). By including this subset of lakes EPA hoped to be able to evaluate changes that occurred between the 1970s and 2007.

In conjunction with the national survey, a number of states opted to sample additional lakes to achieve a state-wide probabilistic survey. EPA provided a list of additional lakes to the states so that any state wishing to conduct a state-scale statistical survey could do so. Sampling and processing methods from these additional lakes had to adhere to both the national field and laboratory protocols. Eight states (MI, WI, IN, MN, TX, OK, ID, and WA) took advantage of the opportunity and the results from the additional sites were analyzed along with the national data. Some states increased the number of sites, but only collected a subset of indicators. Still other states opted to expand the list of indicators to address issues specific to their state; for example, Minnesota used its state-scale survey to assess pesticides.

Figure 2 shows the location of the lakes that were sampled for the NLA. The surveyed lakes cover an area of 3.8 million acres of surface water spread across the national landscape.

The site selection for the survey ensures that EPA can make unbiased estimates concerning the health of the target population of lakes with statistical confidence. The greater the number of sites sampled, the more confidence in the results. The number of sites included in the survey allows EPA to determine the percentage of lakes nationwide and within predetermined ecoregions that exceed a threshold of concern with 95% confidence. In the graphs throughout this report, the margin of error is provided as thin lines on either side of the bars and represent the 95% confidence interval for the estimate.

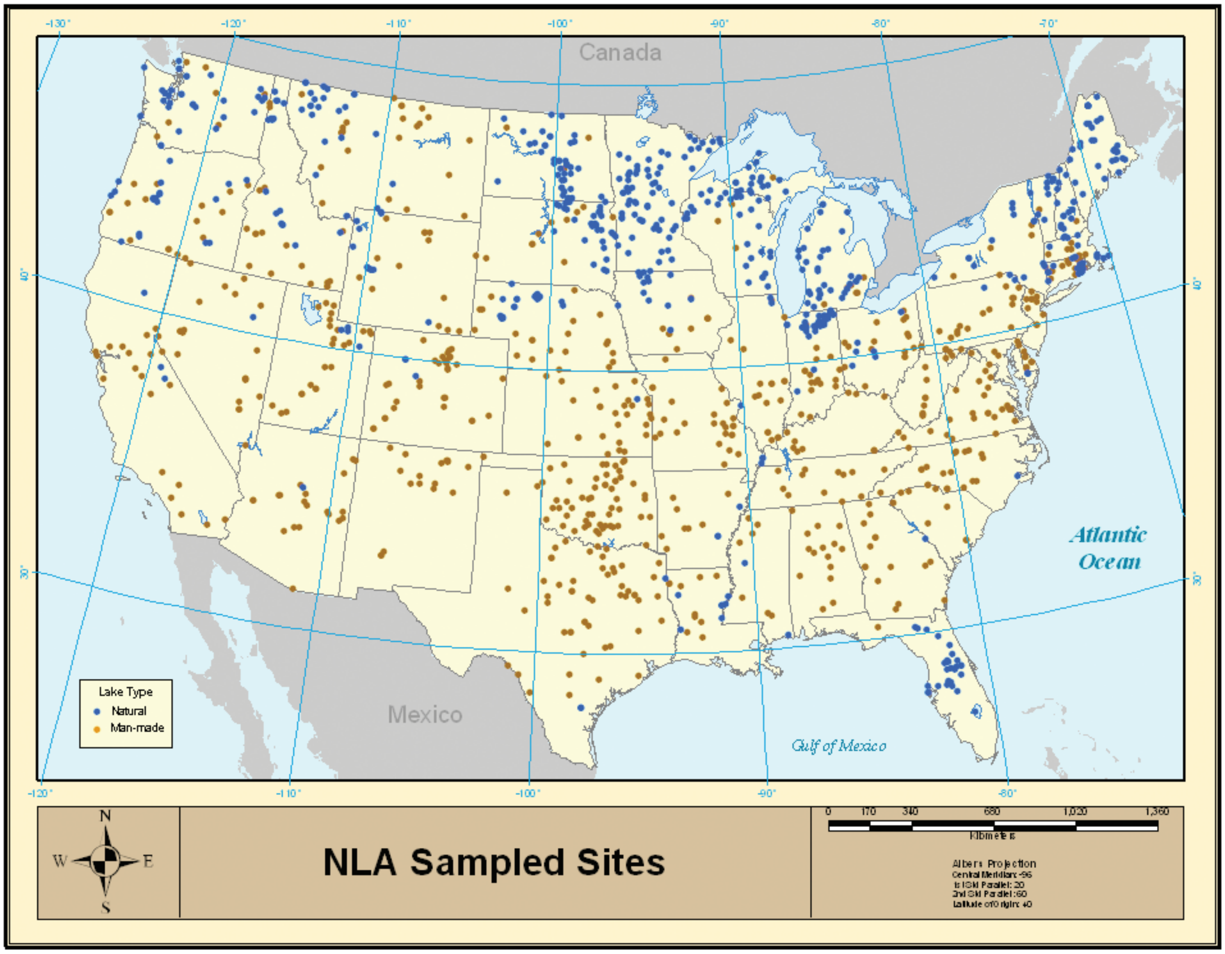


Figure 2. Location of lakes sampled in the NLA. Natural lakes are the blue dots; Man-made lakes are brown.

For national estimates, the margin of error around the NLA findings is approximately ±5% and for ecoregions the margin of error is approximately ±15%. For example, for the national biological condition findings, the NLA estimates that 22.4% of the nation's lakes are in poor condition and that the margin of error is +/- 4%. This means that there is a 95% certainty that the true value is between 18.4% and 26.4%.

Lake Extent - Natural and Man-made Lakes

NLA analysts, comprised of lake science experts both within and outside the Agency, examined available records for each sampled lake to determine its origin. They considered natural lakes as those that existed pre-European settlement, even if presently augmented by means of an impoundment or other earthworks. Using this operational definition, 41% of the estimated 49,546 lakes are man-made reservoirs, while 59% are of natural origin. This means that nearly one-half of today's lakes were not here when the colonists arrived.

While natural lakes come in many different sizes, most man-made lakes are relatively small. A total of 52% of man-made lakes are 10-25 acres (4-10 hectares) in size compared with only 34% of the natural lakes in that small lake size category. Large lakes, over 12,500 acres (5,000 hectares), are rare in the U.S., comprising only 0.3% of natural lakes and 0.6% of man-made lakes (Figure 3).

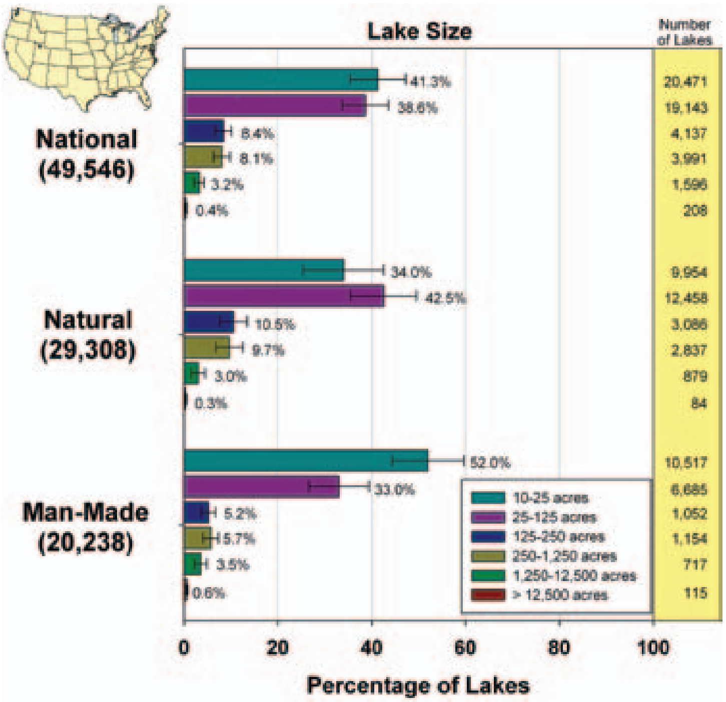


Figure 3. Size distribution of lakes in the U.S. overall and for natural and man-made lakes.

Choosing Indicators

Scientists and lake managers recognize that lake ecosystems are dynamic and indicators selected to characterize lakes must represent important aspects of water resource quality. For the NLA, a suite of chemical, physical and biological indicators were chosen to assess biological integrity, trophic state, recreational suitability, and key stressors impacting the biological quality of lakes.

Although there are many more indicators and/or stressors that affect lakes, NLA analysts believe these to be among the most representative at a national scale. The NLA survey marks the first time all these indicators have been applied consistently and simultaneously to lakes on a national scale.

For this assessment, NLA analysts looked at data of phytoplankton, zooplankton and sediment diatoms in an effort to characterize the biological condition of lakes. It was during the analysis that it was decided that the results of the phytoplankton and zooplankton assessment would serve as the primary biological indicator. To address recreational/human health related concerns, the NLA looked at actual levels of the algal toxin microcystin, along with cyanobacterial cell counts and chlorophyll-*a* concentrations as indicators of the potential for the presence of algal toxins. The presence and concentration of microcystin were used as the primary indicators for recreational condition. Chlorophyll-*a* was used as the primary indicator of trophic status. Although fish samples were not collected in the survey, NLA analysts also looked at the findings of a parallel study of contaminants in fish tissue.

Both physical and chemical stressor indicators were measured. For example, shorelines affect biological communities in many ways, such as providing food and

Biological	Recreational	Chemical	Physical
• Sediment diatoms • Phytoplankton (algae) • Zooplankton • Benthic macroinvertebrates* • Algal density (chlorophyll-*a*) • Invasive species*	• Pathogens* *(enterococci)* • Algal toxin (microcystins) • Algal cell counts (Cyanobacteria) • Algal density (chlorophyll-*a*)	• Nutrients (phosphorus & nitrogen) • Water column profile (dissolved oxygen, temperature, pH, turbidity, acid neutralizing capacity, salinity) • Sediment mercury*	• Lakeshore habitat cover and structure • Shallow water habitat cover and structure • Lakeshore human disturbance

* These indicators are still under evaluation and are not included in this report. Results will be published at a later date.

shelter for aquatic wildlife, and by moderating the magnitude, timing, and pathways of water, sediment, and nutrient inputs. Shorelines also buffer the lake from human activities. Water quality characteristics, such as nutrient levels and dissolved oxygen, create environments essential for aquatic organisms to survive and grow. At the bottom of the lake, sediment diatoms, a type of algae that live on the bottom and leave fossil remains, allow examination of current water quality conditions, such as phosphorus levels, along with historical conditions. These indicators of stress were selected because water quality stressors impact the biological health of lakes– from primary producers (phytoplankton or algae) to small openwater animals (zooplankton) to macroinvertebrates (insects, mollusks and crustaceans) and fish.

Launching a field survey boat in Kansas.
Photo courtesy of Ben Potter.

Lake Habitats

Lakes are highly interactive systems. The physical and chemical make-up of a lake supports a specialized community of biological organisms unique to the surrounding environment. Lakes and ponds are still-water habitats that host a large array of floating organisms that cannot survive in flowing water. For many organisms, shoreline and shallow water habitats provide refuge from predation, living and egg-laying substrates, and food. In addition to aquatic inhabitants, a wide number of terrestrial animals rely on lakes for their food. For example, in a typical summer, a moose can eat over 17½ lbs of aquatic plants per day. A 3½ lb adult osprey can consume some 270 lbs of fish in one year

The indicators include both the vegetation and physical features along shorelines and adjacent upland areas. Shoreline structure affects nutrient cycling, biological production, and even sedimentation rates within the lake. The zone of transition between the lakeshore and the water's edge is an area where considerable biological interactions occur and is critically important to benthic communities, fish, and other aquatic organisms. The relationship between the terrestrial and aquatic environments is characterized by the movement of nutrients/food from the shore to the water (*e.g.,* fish making use of emergent plants for food or shelter), and the reverse movement from the water back to the shore (*e.g.,* seasonal flooding of shorelines, shore birds feeding on aquatic insects and crustaceans).

Human activities along lakeshores often adversely affect ecosystem functions by lessening the amount and type of optimal habitat available. Habitat cover or protection, in the form of woody snags, overhanging trees, and aquatic plants, becomes markedly reduced. A poor habitat cover adversely impacts aquatic plants, fish, and other living things in and around the lake. Alterations of these and other types of habitat features can affect biological integrity even in lakes where the water is not polluted. Therefore, the physical habitat condition of the land-water interface is critically important to overall lake condition.

Field Sampling

In preparation for the survey, each target lake was screened to verify that it met the established criteria for inclusion in the survey. Throughout the summer of 2007, 86 field crews, consisting of 2 to 4 people each, sampled lakes from Maine to California. To ensure consistency in data collection and quality assurance, the crews attended a three-day training session, used standardized field methods and data forms, and followed strict quality control protocols including field audits.

At each lake site, crews collected samples at a single station located at the deepest point in the lake and at ten stations around the lake perimeter (Figure 4). At the mid-lake station, depth profiles for temperature, pH, and dissolved oxygen were taken with a calibrated water quality probe meter or multi-probe sonde. A Secchi disk was used to measure water clarity and depth at which light penetrates the lake (the euphotic zone). NLA analysts used these vertical profile measurements to determine the extent of stratification and the availability of the appropriate temperature regime and level of available oxygen necessary to support aquatic life. Single grab water samples were collected to measure nutrients, chlorophyll-*a*, phytoplankton, and the algal toxin microcystin. Zooplankton samples were collected using a fine mesh (80µm) and course mesh (243µm) conical plankton net.

A sediment core was taken to provide data on sediment diatoms and mercury levels. The top and bottom layers of the sediment core were analyzed to detect possible changes in diatom assemblages over a period of time.

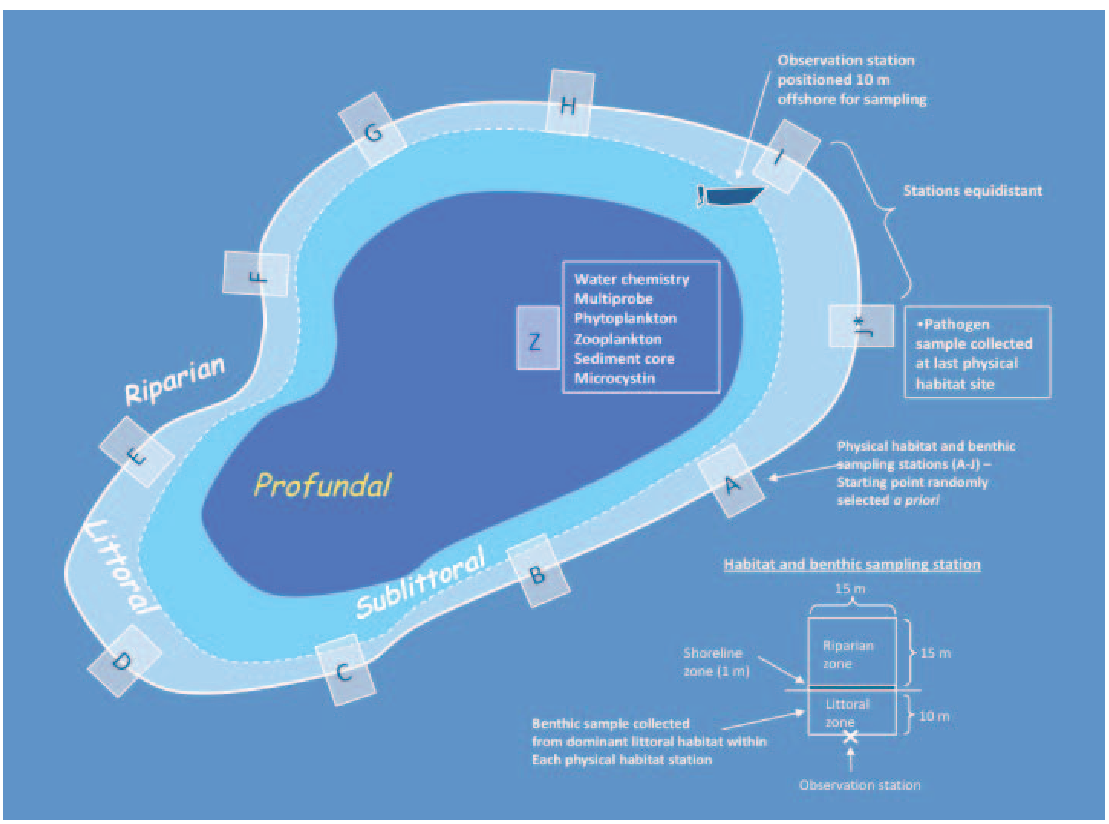


Figure 4. NLA sampling approach for a typical lake. Sampling locations are denoted by letters A-J and Z. Riparian, littoral, sublittoral, and profundal lake zones are depicted, as is the schematic design of a shoreline physical habitat station.

Along the perimeter of the lake, crews collected data and information on the physical characteristics that affect habitat suitability. Information on substrate composition was recorded along the ten pre-determined stations. Benthic macroinvertebrates, collected with a 500μm D-frame net, and water samples for pathogen analysis were collected at the first and last station, respectively. Filtering and other sample preparations took place back on shore. Sampling each lake took a full day and many crews spent weeks in the field. At the end of the season, field crews collected 8,536 water and sediment samples; took over 5,800 direct measurements; and recorded in excess of 620,000 observations.

Setting Expectations

Two types of assessment thresholds were used in the NLA. The first is fixed thresholds. Fixed thresholds are based on longstanding accepted values from the peer reviewed scientific literature. They are well established, and widely and consistently used. An example of this is standard chlorophyll-a thresholds which are used to classify lakes into the different trophic categories.

The second type of threshold is based on the distribution (*i.e.,* the range of values) of a particular indicator derived from the reference lakes data.

Selecting Reference Lakes

In order to assess the condition of the country's lakes, results were compared to conditions in a suite of "reference lakes." A reference lake in the NLA is a lake (either natural or man-made) with attributes (such as biological or water quality) that come as close as practical to those expected in a natural state, *i.e.*, least-disturbed lake environment. NLA analysts used the reference distribution as a benchmark for setting thresholds for good, fair, and poor condition for each of the indicators.

EPA's experience with past surveys showed that only a small portion of the sampled population of lakes will be of reference quality. EPA used both identified lakes that were thought to be of high quality as well as high quality lakes from the random site selection process to serve as candidate reference lakes that might ultimately serve as "least-disturbed" benchmark reference sites. The candidate lakes were sampled identically to, and in addition, to the target lakes. Subsequently, data results from all sampled lakes were evaluated against the reference screening criteria to determine the final set of lakes that would be used to characterize the reference condition. NLA analysts used a number of independent variables reflecting human influence as classification and screening criteria, *e.g.*, limnological shoreline index, chloride content, total water column calcium, and others. Two parallel groups of reference lakes were set, one for biological condition, and another for

Retrieving a sediment core.
Photo courtesy of Great Lakes Environmental Center.

nutrient stressors. The latter set of reference sites was developed so that nutrient levels could be used in screening reference lakes for biological condition.

When considering reference condition, it is important to remember that many areas in the United States have been altered - with natural landscapes transformed by cities, suburban sprawl, agricultural development, and resource extraction. To reflect the variability across the American landscape, these least-disturbed lakes diverge from the natural state by varying degrees. For example, highly remote lakes like those in the upper elevation wilderness areas of Montana may not have changed in centuries and are virtually pristine, while the highest quality, least-disturbed lakes in other parts of the country, especially in urban or agricultural areas, may exhibit different levels of human disturbance. The least-disturbed reference sites in these widely influenced watersheds display more variability in quality than those in watersheds with little human disturbance. Thus in reference conditions across the country, *i.e.,* the "bar" for expectations may be different. The resulting reference lakes represent the survey team's best effort at selecting lakes that are the least disturbed nationally and in specific regions across the country.

Thresholds – Good, Fair, and Poor

After the reference lakes were selected and reference condition was determined, thresholds against which the target lakes are compared were set. For NLA, each indicator for a lake was classified as either "good," "fair," or "poor" relative to the conditions found in reference lakes. That is, "good" denotes an indicator value similar to that found in reference lakes, "poor" denotes conditions definitely different from reference conditions, and "fair" indicates conditions on the borderline of reference conditions. Specifically, these thresholds are then applied to the results from the target lakes and are classified as follows: lake results above 25% of the reference range values are considered "good;" below the 5% of the reference range value are "poor;" and those between the 5% and 25% are "fair" (Figure 5). These "good," "fair," "poor" designations however are not intended to be a replacement for the evaluation by states and tribes of the quality of lakes relative to specific water quality standards.

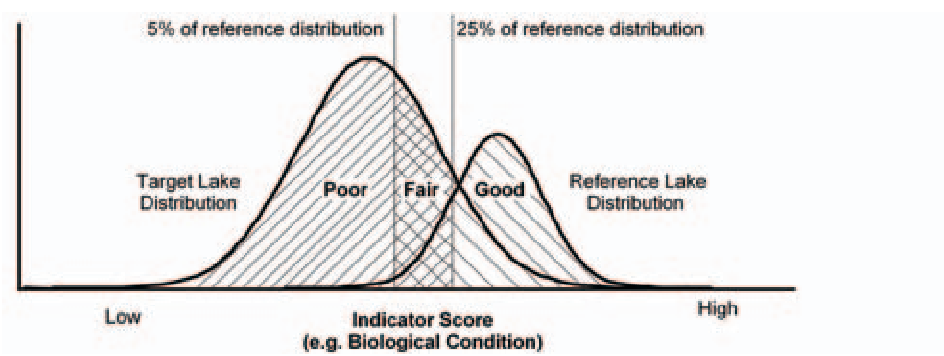


Figure 5. Reference condition thresholds used for good, fair, and poor assessment.

HIGHLIGHT

Surveying the Nation's Lakes for Invasive Aquatic Species

Amy P. Smagula
New Hampshire Department of Environmental Services

On every continent, in nearly all aquatic habitat types, at all levels of the food web, invasive species have made an impact. Invasive aquatic species can be described as those species that live in water but are generally not native to a particular waterbody. In general they have traits or characteristics that suggest a competitive ecological advantage over native species. Invasive species grow rapidly and/or aggressively, so that they can eventually dominate a habitat to the detriment of native creatures that already live there. Invasive aquatic species include a whole range of organisms, including plants, animals, pathogens, and others.

Invasive Aquatic Species:

- Grow very quickly and spread rapidly to occupy large areas;
- Have various strategies for reproduction;
- Survive in a range of conditions;
- Have no natural predators to control them;
- Take over areas from native plants/animals and can thus be ecologically devastating;
- Pose serious economic problems in terms of control costs and costs attributable to habitat loss and recreational impairments to waterbodies, including reductions in property values on infested waterbodies;
- Are very difficult if not impossible to control; and
- Threaten nearly half of the species listed under the Endangered Species Act.

The types of invasive aquatic species in our lakes are numerous and diverse, and can include aquatic plants that either root in substrate (like Eurasian watermilfoil or Hydrilla) or that float on the surface of the water (like the giant salvinia). They include larger animals such as fish (like the snakehead fish), and macroinvertebrates (like the zebra mussel). They also include those seen only with the aid of a microscope, such as filamentous algae or the spiny water flea.

The pathways for invasive aquatic species introductions are varied, and include ballast water discharges from large vessels, retail industries like the aquarium and home water garden trades, and even internet suppliers of aquatic species. Once a species becomes established in a waterbody, either by accidental (*e.g.*, contaminated boat) or intentional means (*e.g.*, dumping of an aquarium or direct planting), it is transient recreational equipment (motor boats, kayaks, diving gear, *etc.*) that causes the lake-to-lake spread of these species.

Depending on the point of introduction and transport pathways, species can become widely distributed or remain as localized infestations. Unfortunately, many invasive aquatic species are highly adaptive, and can survive and thrive in a wide range of environmental conditions. Big or small, plant or animal, invasive aquatic species in our lakes can have detrimental effects on the very attributes of those waterbodies that scientists, citizens, and environmental stewards are trying to evaluate and preserve.

How Can Data from the NLA Survey Help?

One of the goals of the National Lakes Assessment (NLA) is to provide citizens and governments with current information on the health of our lakes so that they can take action to prevent further degradation. Data on invasive aquatic species can be used to help determine which of these species has been documented in a state or region, and if those are well established populations or if they are pioneering and can be eliminated or halted before other waterbodies in the area are affected. These data may also be used to assist with risk assessments for an area, based on what has been found in neighboring states, coupled with tourism and recreational data for that region.

The Key is Prevention, Early Detection, & Rapid Response

Preventing the introduction of invasive aquatic species is paramount to protecting a waterbody. Many states and regional working groups have established education campaigns to alert lake users and others about the threats posed by invasive aquatic species and to hopefully prevent a new infestation by proper care of transient recreational vessels and gear. Additionally, many states have developed prohibited species lists in an effort to prevent overland transport and sale of these invasive species.

When prevention fails and an infestation does occur, early detection is critical. Individual lake associations, special interest groups, and homeowners are encouraged to look for new infestations on a regular basis during the growing season, particularly if they live on a waterbody that receives a high level of use by transient boaters. A small new infestation is much more easily contained or eradicated than a dense and large-scale infestation. A network of volunteer monitors around a waterbody can look for signs of invasive species and report to key officials who can effectively deal with a potentially new infestation.

State officials should be knowledgeable and poised for a rapid response to contain and control an infestation. They should be aware of appropriate management actions for the species in question and how to best approach the problem. Fortunately, many states have developed specific plans for aquatic nuisance species management, so that an immediate response can be made.

Hydrilla ***(Hydrilla verticillata)***	**First Identified in US:** 1960 **Native Range:** Africa **U.S. Distribution:** Widespread throughout the east and southeast, CA as well as occurrence in other states in the U.S. **Description:** Narrow leaves whorled around the 20 ft main stem. It is the most invasive submergent plant in the U.S., and can even out-compete invasive watermilfoil by canopying over the surface. It has been observed to grow up to a half-inch per day in optimum conditions. **Impacts:** This plant forms thick impenetrable growth in the water column of lakes. It can impact native aquatic plants and animals and cause problems for recreation and navigation on waterbodies that it infests.	
Zebra mussel ***(Dreissena polymorpha)***	**First Identified in US:** 1988 **Native Range:** Eurasia **U.S. Distribution:** All of the Great Lakes and many associated tributaries, plus other states throughout the U.S. **Description:** Sticky strands secreted from one side of shell. Can grow very thick on surfaces. **Impacts:** Documented to grow very thick on surfaces, foul marine engines, clog intake pipes, wash up in windrows on beaches, and alter the aquatic food web by reducing the amount of algae in the water due to high filter-feeding rates.	

Photos credits: Hydrilla, Amy P. Smagula, NH DES. Zebra mussels, NH SeaGrant.

CHAPTER 3. THE BIOLOGICAL CONDITION OF THE NATION'S LAKES

IN THIS CHAPTER

- Lake Health – The Biological Condition of Lakes
- Stressors to Lake Biota
- Ranking of Stressors

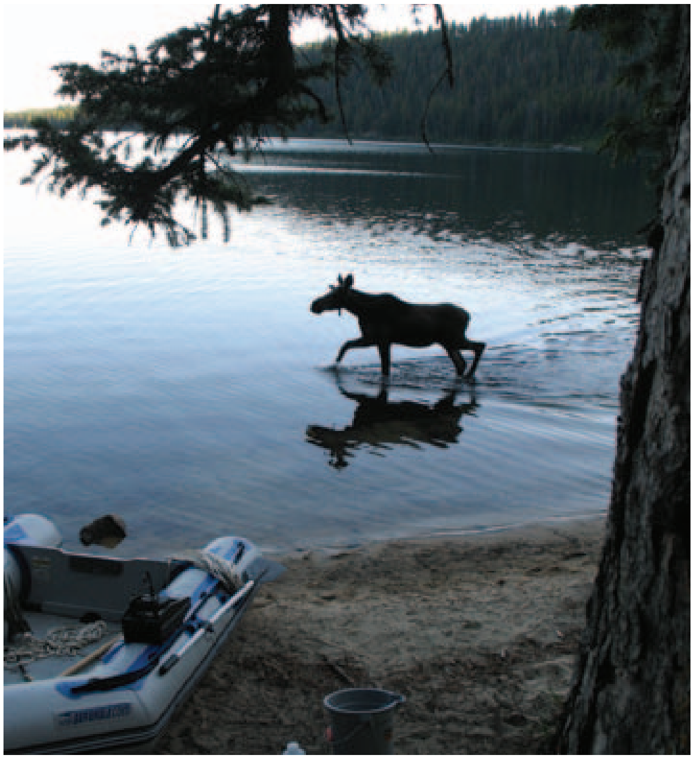


Photo courtesy of Great Lakes Environmental Center

Chapter 3
The Biological Condition of the Nation's Lakes

The Clean Water Act explicitly aims "to restore and maintain the chemical, physical and biological integrity of the nation's waters". Although the NLA report does not include all aspects of biological integrity or review all possible chemical, physical or biological stressors known to affect water quality, it does present the findings of some important indicators for estimating the condition of the nation's lakes and characterizing the key influences.

This and the following two chapters describe the results of the NLA using three approaches to assess lake condition. The first approach evaluates whether lakes are able to support healthy aquatic plant and animal communities. Analysts evaluated key stressors to lake biota, such as chemical and physical habitat attributes, and ranked the stressors in order of importance. In the second approach, the recreational suitability of lakes was assessed and the risk of exposure to algal toxins was evaluated (Chapter 4). The third approach was to evaluate trophic state based on chlorophyll-*a* levels (Chapter 5).

Lake Health – The Biological Condition of Lakes

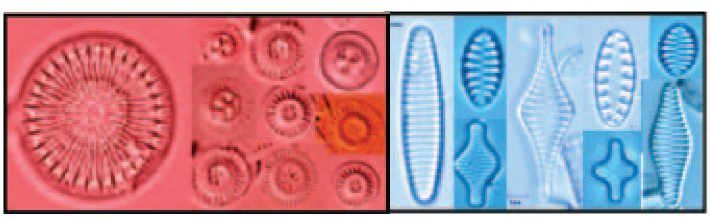
The biology of a lake is characterized in terms of the presence, number, and diversity of fish, insects, algae, plants and other organisms that together provide accurate information about the health and productivity of the lake ecosystem. The number and kinds of plant and animal species present in a lake system are a direct measure of a lake's overall well-being.

The biological condition assessment is based on information from two biological communities or assemblages – phytoplankton and zooplankton — in its evaluation of lake condition. The primary basis for assessing biological health is an index of taxa loss which is applied to the phytoplankton and zooplankton data. The NLA uses a measure of planktonic taxa loss as the predominant measure of overall lake condition because it is based on both plant and animal data and thus will reflect a broader perspective of trends in lakes. A second method to assess biological health uses an index of biotic integrity that is applied to sediment diatoms, a distinct type of phytoplankton. Both models use the biological reference conditions developed from the set of reference lakes.

Biological Indicators

Phytoplankton. Phytoplankton are microscopic plants (algae) that float in the water and are usually responsible for both the color and clarity of lakes. Because of their ability to photosynthesize (*i.e.,* they use the sun's energy to turn carbon dioxide and water into food and energy), they are a primary source of energy in most lake systems, providing the food source for higher order organisms such as zooplankton or small fishes. Phytoplankton are remarkably diverse. For example, certain phytoplankton can regulate the depth at which they reside, optimizing their ability to access both nutrients and light. Others are specific to certain habitats within lakes, and to certain nutrient and chemical conditions.

Zooplankton. Zooplankton are small free-floating aquatic animals. The zooplankton community constitutes an important element of the aquatic food chain. These organisms serve as an intermediary species in the food chain, transferring energy from planktonic algae (primary producers) to larger invertebrate predators and fish. Both phytoplankton and zooplankton are highly sensitive to changes in the lake ecosystem. The effects of environmental disturbances can be detected through changes in species composition, abundance, and body size distribution of these organisms.



Centrate (left) and pinnate (right) diatoms.
Image courtesy of J. Smol as provided by D. Charles.

Diatoms. Diatoms are a group of algae. Typically abundant in marine and freshwater habitats, diatoms account for at least 20% of the primary production of energy on earth. Unique among the algae, diatoms have cell walls composed of silica (glass), which are intricate and beautiful as well as useful

Collecting a zooplankton sample in Texas.
Photo courtesy of Texas Commission of Environmental Quality.

for identifying individual species. In lakes, diatoms grow suspended in water as well as attached to substrates. Biologists use the diatoms in the water column and those on the lake bottom as a reflection of conditions in the lake. When diatoms die, they settle to the bottom and their silica shells remain intact. Over time their silica shells are preserved in layer upon layer of lake sediments enabling researchers to look at conditions that existed in the past. Similar to other biological indicators, diatoms integrate the physical and chemical conditions of the lake and surrounding watershed in which they reside. The environmental conditions under which particular diatom species flourish vary greatly and have been well described, making them a useful indicator.

Index of Taxa Loss – The Observed/Expected (O/E) Ratio

NLA analysts used the planktonic O/E taxa loss model to assess the condition of the planktonic community, combining data from both phytoplankton and zooplankton. The O/E measure looks at whether or not organisms (taxa) one would expect to find, based on reference lakes, are in fact present. The model allows a precise matching of the taxa found in the sample — in this case phytoplankton and zooplankton taxa — with those that should occur under the specified natural environmental conditions defined by the reference sites. The list of expected taxa (or "E") at individual sites are predicted from a model developed from data collected at reference sites. By comparing the list of taxa observed (or "O") at a site with those expected to occur, one can quantify the proportion of taxa that have been lost presumably due to stressors present in the lake. The O/E model is widely used nationally and internationally to assess the condition of aquatic communities. The index is particularly attractive because it allows a direct comparison of conditions across the different types of aquatic systems (*e.g.*, lakes, wetlands, streams, and estuaries) that will be assessed by the national aquatic resource surveys.

Measuring physical habitat data with flooded terrestrial vegetation. Photo courtesy of Dave Mercer.

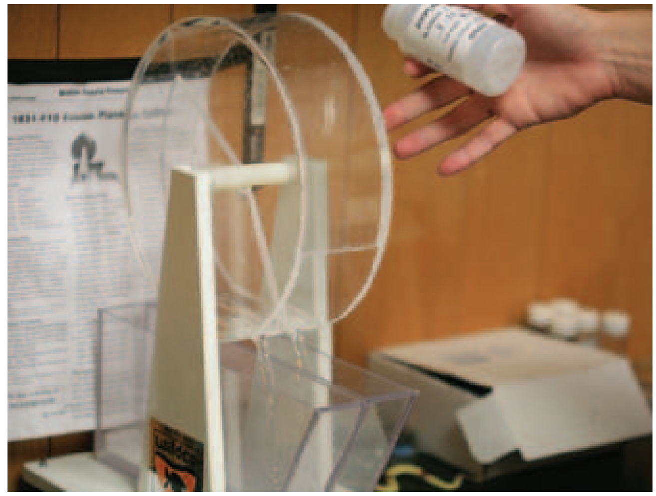
Typically O/E values are interpreted as the percentage of the expected taxa present. Each tenth of a point less than 1 represents a 10% loss of taxa at the site; thus, an O/E score of 0.9 indicates that 90% of the expected taxa are present and 10% are missing. The higher the percentage, the healthier the lake. As with all indicators, O/E values must be interpreted in context of the quality of reference sites because the quality of reference sites available in a region sets the bar for what taxa may be expected. Regions with lower-quality reference sites may have fewer taxa or different taxa and thus will have a lower bar. Although an O/E value of 0.8 means the same thing regardless of a region, *i.e.*, 20% of taxa have been lost relative to reference conditions in each region, the true amount of taxa loss will be under-estimated if reference sites are of lower quality, meaning more disturbed than reference sites in comparable regions.

For the phytoplankton and zooplankton data, NLA analysts developed regionally-specific O/E models to predict the extent of taxa loss across lakes of the United States. They defined three categories of plankton taxa loss: good (<20% taxa loss), fair (20-40% taxa loss), and poor (>40% taxa loss).

Index of Biological Integrity - The Lake Diatom Condition Index

The Lake Diatom Condition Index (LDCI) — or the Diatom IBI — is similar in concept to an economic indicator (*e.g.*, the Consumer Confidence Index) in that the total index score is the sum of scores for a variety of individual measures. To calculate economic indicators, economists look at a number of metrics, including new orders for consumer goods, building permits, money supply, and others that reflect economic growth. To determine the LDCI, ecologists looked at taxonomic richness, habit and trophic composition, sensitivity to human disturbance, and other aspects of the assemblage that are reflective of a natural state. For the LDCI, NLA analysts calculated regionally-specific thresholds that were based on percentages of reference lake distributions of LDCI values.[2]

The development of the LDCI is a groundbreaking addition to the tools available to perform lake assessments. The metrics used to develop the LDCI for the NLA covered five characteristics of diatom assemblages that are routinely used to evaluate biological condition:



Subsampling zooplankton samples.
Photo courtesy of EcoAnalysts.

Taxonomic richness: This characteristic represents the number of distinct taxa, or groups of organisms, identified within a sample. A greater number of different kinds of taxa, particularly those that belong to pollution-sensitive groups, indicate a variety of physical habitats and an environment exposed to generally lower levels of stress.

Taxonomic composition: Ecologists calculate composition metrics by identifying the different taxa groups, determining which taxa in the sample are ecologically important, and comparing the relative abundance of organisms in those taxa to the whole sample. Healthy (good quality) lake systems have diatoms from across a larger number of taxa groups, whereas stressed (poor quality) lakes are often dominated by a high abundance of organisms in a small number of taxa that are tolerant of pollution.

Taxonomic diversity: Diversity metrics look at all the taxa groups and the distribution of organisms among those groups. Healthy lakes should have a high level of diversity of diatoms present.

Morphology: Organisms are characterized by certain adaptations, including how they move and where they live. These habits are captured in morphological metrics. For example, some are designed to move freely up and down within the water column to maximize nutrient uptake or light exposure, while others may develop adaptations, such as coloration, to avoid predation. A diversity of such attributes is reflective of a lake that naturally includes a diversity of habitat niches.

Pollution tolerance: Each taxa can tolerate a specific range of chemical contamination, which is referred to as their pollution tolerance. Once this range is exceeded, the taxa are no longer present. Highly sensitive taxa, or those with a low pollution tolerance, are found only in lakes with good water quality.

[2] The numerical threshold for the diatom index and many of the other NLA indicators can be found in the Technical Appendix.

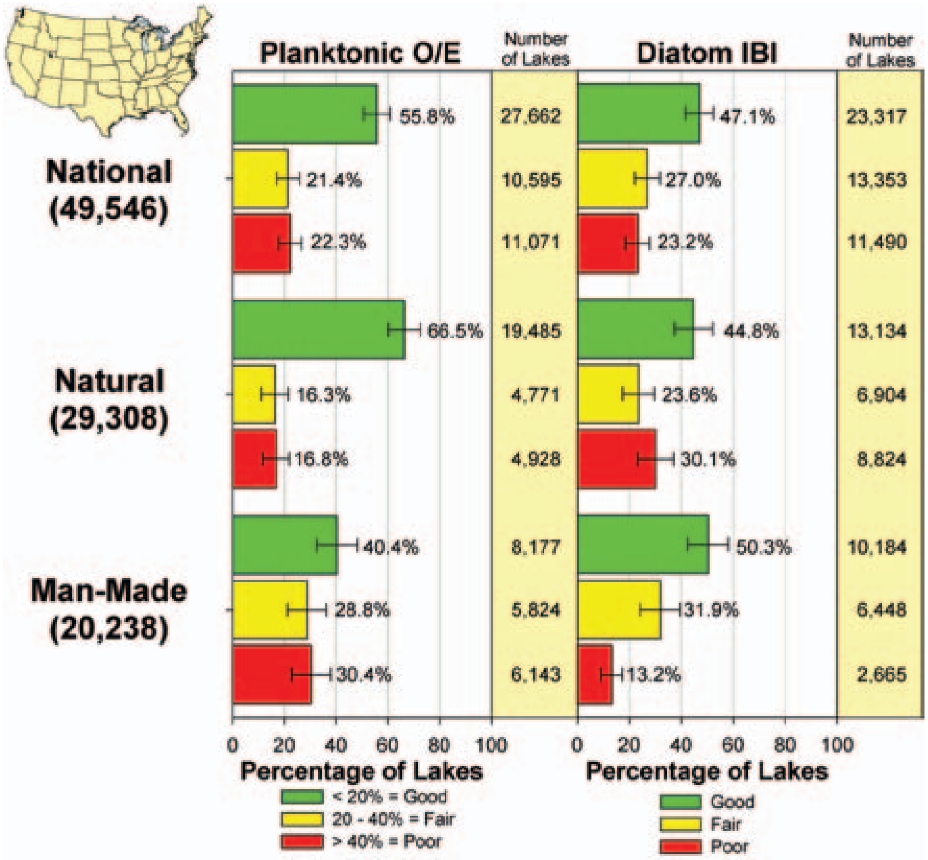


Figure 6. Assessment of quality using the Planktonic O/E Taxa Loss and Lake Diatom Condition Index.[3]

Findings of the Biological Assessments

Using the planktonic O/E, or taxa loss model, 56% of the nation's lakes are in good condition, while 21% are in fair condition, and 22% are in poor condition (Figure 6). The LDCI shows similar results with 47% of lakes in good condition, 27% in fair condition, and 23% in poor condition. For the continental U.S., this means about half of the country's lakes are in good condition, while the other half are experiencing some level of stress that is negatively affecting the aquatic biological communities.

Natural lakes in general exhibit slightly lower overall plankton taxa loss than man-made lakes. Sixty-seven percent of natural lakes are in good condition as compared to 40% of man-made lakes - a statistical difference. The LDCI, on the other hand, indicates that the proportion of lakes exhibiting good conditions does not vary significantly between natural and man-made lakes. However, 30% of natural lakes as compared to 13% of man-made lakes exhibit poor biological condition based on the diatom LDCI.

Although in many cases the results of the planktonic O/E analysis are similar to the results of the diatom LDCI analysis, such agreement will not always occur. The taxa loss index examines a specific aspect of biological condition (biodiversity loss) and the index of biological integrity analysis

[3]For this and all figures in this report, values for good, fair and poor may not add to one hundred percent. Lakes sites that were not assessed and indicators for which no data was recorded are not included. Please refer to the Technical Appendix for further discussion.

combines multiple characteristics to evaluate biological condition. In this instance, the two communities may be responding differently to the stresses impacting lakes or to different stresses.

Stressors to Lake Biota

In the aquatic environment, a stressor can be anything (chemical, biological or physical) that has the potential to impact its inhabitants by altering their surroundings outside their normal ecological range. There are many external occurrences that can alter a creature's ability to thrive, both natural and otherwise. Drought or rapid draw-down can be a stressor; contaminant (*e.g.,* metals) can be a stressor; and human activity can be a stressor. An important dimension of the national lakes assessment is to evaluate key chemical and physical stressors of lake quality that, when altered, have the potential to impact lake biota.

1. Chemical Stressors

For the assessment, five of the eight chemical indicators of lake stress were evaluated. These are total phosphorus concentration, total nitrogen concentration, turbidity, acid neutralizing capacity (ANC), and dissolved oxygen concentration (DO).

Phosphorus, Nitrogen, and Turbidity

Phosphorus and nitrogen are critical nutrients required for all life. In appropriate quantities, these nutrients support the primary algal production necessary to support lake food webs. In many lakes, phosphorus is considered the "limiting nutrient," meaning that the available quantity of this nutrient controls the pace at which algae are produced in lakes. This also means that modest increases in available phosphorus can cause very rapid increases in algal growth.

Some lakes are limited by nitrogen. In these lakes, modest increases in available nitrogen will yield the same effects. When excess nutrients from human activities enter lakes, cultural eutrophication is often the result. The culturally-accelerated eutrophication of lakes has a negative impact on everything from species diversity to lake aesthetics.

Turbidity is a measure of light scattering, specifically, murkiness or lack of clarity. Lakes that are characterized by high concentrations of suspended soil particles and/or high levels of algal cells will have high measured turbidity. Turbidity in lakes is natural in some instances, resulting from natural soil deposition and resuspension within the lakes themselves. When human activities in lake watersheds and riparian zones increase soil erosion, increased turbidity often results in smothering of nearshore habitats by sediments and/or changing algae growth patterns. These changes affect biological and recreational conditions.

Boat fully loaded for a day on an Oklahoma lake.
Photo courtesy of Paul Koenig.

Findings for Nutrients and Turbidity

Phosphorus, nitrogen, and turbidity are linked indicators that jointly influence both the clarity of water and the concentrations of algae in a lake. The levels of these three indicators vary regionally, as do the relationships between nutrients and turbidity, and between nutrients and algal growth. For phosphorus, nitrogen, and turbidity, lakes were assessed in relation to regionally-specific thresholds based on the distributions in a distinct set of reference lakes.

Survey results show that slightly over half of the nation's lakes are in good condition with respect to phosphorus and nitrogen (Figure 7). Fifty-eight percent and 54% of lakes are not stressed for the two nutrients, respectively. For all lake classes there was no significant difference between phosphorus and nitrogen indicators. For both nutrients, there are no significant differences between natural lakes and man-made lakes.

For turbidity, 78% of lakes are in good condition, 16% are in fair condition, and 6% are in poor condition. When comparing the natural lakes to the man-made lakes for this indicator, 75% of natural lakes are in good condition as compared to 81% of man-made lakes.

Lake Acidification

While not a widespread problem, lake acidification continues to be an important indicator of lake condition in a small number of areas around the country. Acid rain and acid mine drainage are major sources of acidifying compounds and can change the pH of lake water, impacting fish and other aquatic life. Acid neutralizing capacity

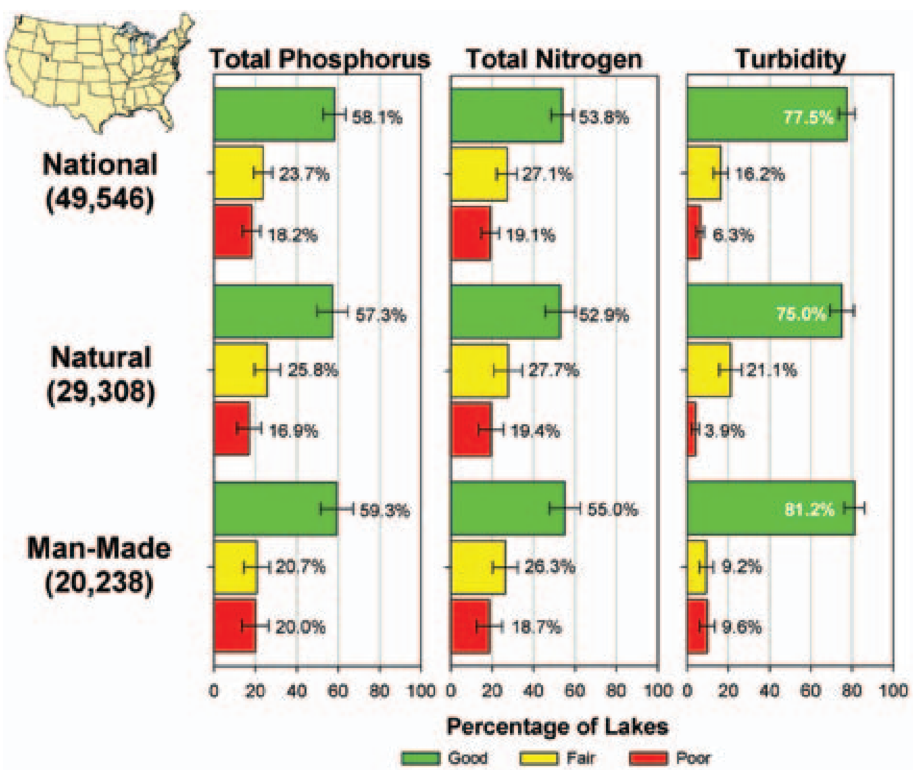


Figure 7. Phosphorus, nitrogen, and turbidity in three lake classes.

ANC Assessment Thresholds	
Non-acidic	>50 µeq ANC
Acidic-natural	≤ 50 µeq ANC and DOC ≤ 5 mg/L
Anthropogenically acidified	≤0 µeq ANC and DOC < 5 mg/L

(ANC) serves as an indicator for sensitivity to changes in pH. The ANC of a lake is determined by the soil and underlying geology of the surrounding watershed. Lakes with high levels of dissolved bicarbonate ions (*e.g.,* limestone watersheds) are able to neutralize acid depositions and buffer the effects of acid rain. Conversely, watersheds that are rich in granites and sandstones and contain fewer acid-neutralizing ions have low ANC and therefore a predisposition to acidification.

Maintaining stable and sufficient ANC is important for fish and aquatic life because ANC protects or buffers against drastic pH changes in the waterbody. Most living organisms, especially aquatic life, function at the optimal pH range of 6.5 to 8.5. Sufficient ANC in surface waters will buffer acid rain and prevent pH levels from straying outside this range. In naturally acidic lakes, the ANC may be quite low, but the presence of natural organic compounds in the form of dissolved organic carbon, or DOC, can mitigate the effects of pH fluctuations.

Findings for Lake Acidification

Results from the NLA indicate that almost all, or 99%, of the nation's lakes can be classified as in good condition with respect to ANC (Figure 8). When looking at these results, however, it is also important to note that although the NLA indicates that lake acidification is not a widespread problem, acidification on a smaller scale, *i.e.*, "hot spots," do occur. While only a relatively small proportion of lakes may be impacted by acidification, the effects of acidification in the impacted lakes, and the contribution of acidity to other stressors, can be severe in specific geographic regions.

Dissolved Oxygen

Dissolved oxygen, or DO, is considered one of the more important measurements of water quality and is a direct indicator of a lake's ability to support aquatic life. Aquatic organisms have different DO requirements for optimal growth and reproduction. Decreases in DO can occur during winter or summer when the available dissolved oxygen is consumed by aquatic plants, animals, and bacteria during respiration. While each organism has its own DO tolerance range, generally levels below 3 mg/L are of concern. Conditions below 1 mg/L are referred to as hypoxic and are often devoid of life.

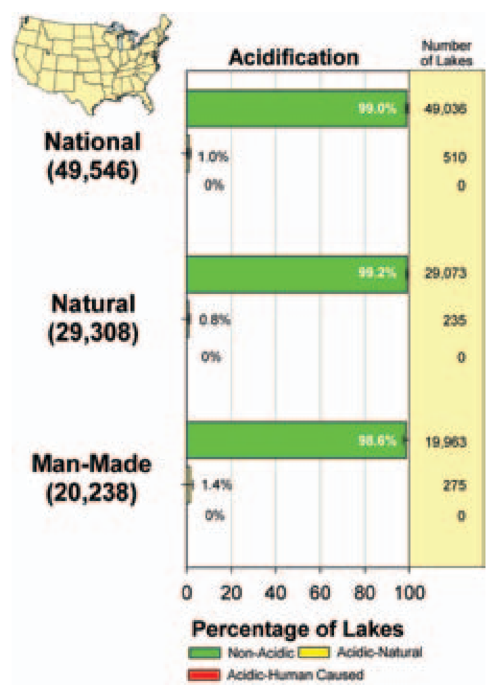


Figure 8. Acid neutralizing capacity for lakes of the U.S.

Findings for Dissolved Oxygen

For the NLA, DO assessment thresholds were established as high (≥ 5 mg/L), moderate (>3 to <5), and low (≤3 mg/L), and were based on measurements from the top two meters in the middle of the lake (Figure 9). Eighty-eight percent of the country's lakes display high levels of DO and are in good condition based on the surface waters sampled (Figure 9). Natural lakes perform slightly better than the nation as a whole with 94% in good condition. Man-made lakes results show 80% with high levels of DO.

These findings indicate that, in general, low DO is not a chronic problem near the lake surface, which was not surprising given the sampling approach used in the survey. Future surveys may be able to more adequately address DO conditions in the bottom waters of lakes where low DO conditions are more likely to occur first.

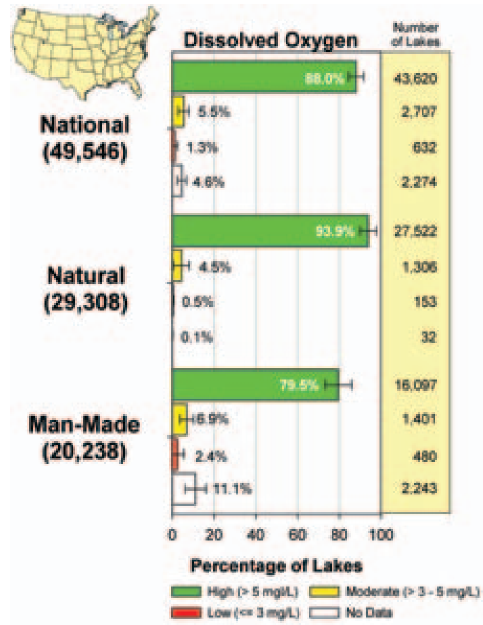


Figure 9. Dissolved oxygen for lakes of the U.S.

2. Physical Stressors

The condition of lakeshore habitats (Figure 10) provides important information relevant to lake biological health. For the NLA, physical habitat condition was assessed based on observations for four indicators: 1) lakeshore habitat, 2) shallow water habitat, 3) physical habitat complexity (an index of habitat condition at the land-water interface), and 4) human disturbance (extent and intensity of human activity). In assessing the physical habitat complexity indicator, NLA analysts looked at not only the total amount of cover present but also the diverse types of cover and the complex nature of potential ecological niches. For each lake habitat indicator, values were compared to the distribution of the indicator value in the reference sites.

Lakeshore Habitat

The lakeshore habitat indicator examines the amount and type of shoreline vegetation. It is based on observations of three layers of coverage (understory grasses and forbs, mid-story non-woody and woody shrubs, and overstory trees). In general, lakeshores are in better condition when shoreline vegetation cover is high in all three layers. It is important to note, however, that not all three layers naturally occur in all areas of the country. For example, in the Northern Plains areas, there is typically no natural overstory tree cover. Similarly, in some areas of the intermountain west, steep rocky shores are the norm for high-mountain and/or canyon lakes. These natural features have been factored into the calculation of the lakeshore habitat indicator.

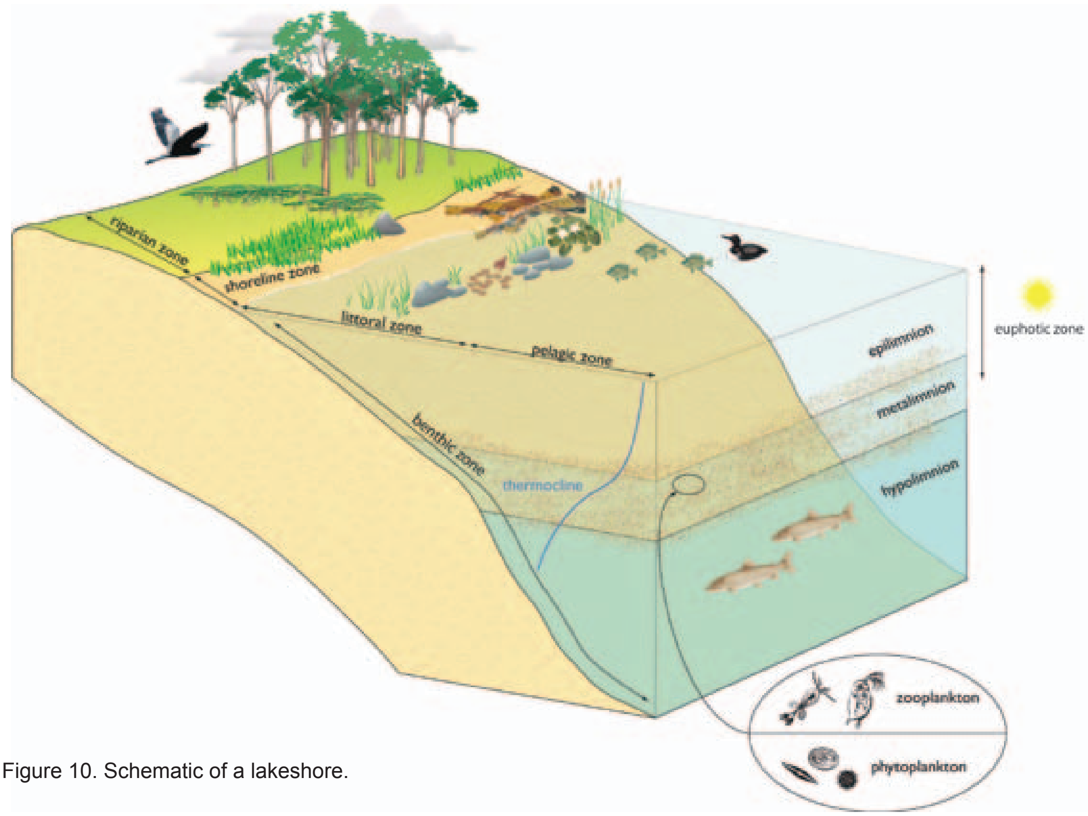


Figure 10. Schematic of a lakeshore.

Shallow water habitat

The shallow water habitat indicator examines the quality of the shallow edge of the lake by utilizing data on the presence of living and non-living features such as overhanging vegetation, aquatic plants (macrophytes), large woody snags, brush, boulders, and rock ledges. Lakes with greater and more varied shallow water habitat are typically able to more effectively support aquatic life because they have more, and more complex, ecological niches. Like the lakeshore habitat indicator, the shallow water indicator is related to conditions in reference lakes and is modified regionally to account for differing expectations of natural condition.

Physical habitat complexity

The third indicator, physical habitat complexity, combines data on from the lakeshore and shallow water interface. This indicator estimates the amount and variety of all cover types at the water's edge. Like the other indicators, this index is related to conditions in reference lakes and is modified regionally to account for differing expectations of natural condition.

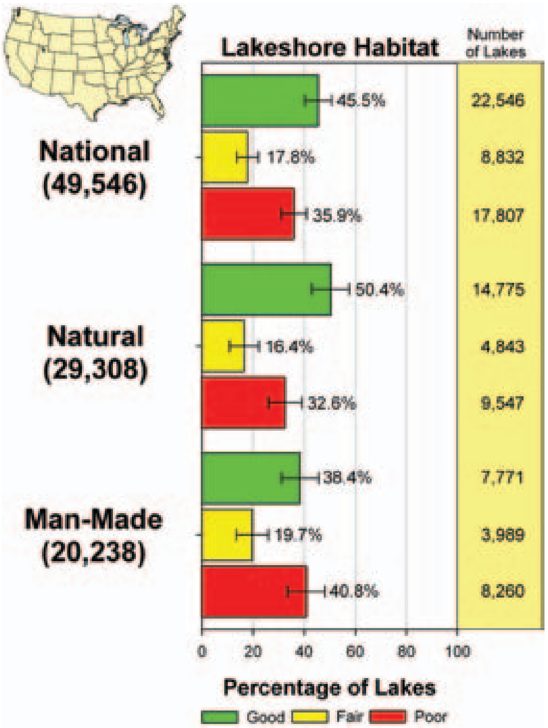


Figure 11. Lakeshore habitat for lakes of the U.S. as percent of lakes in three condition classes.

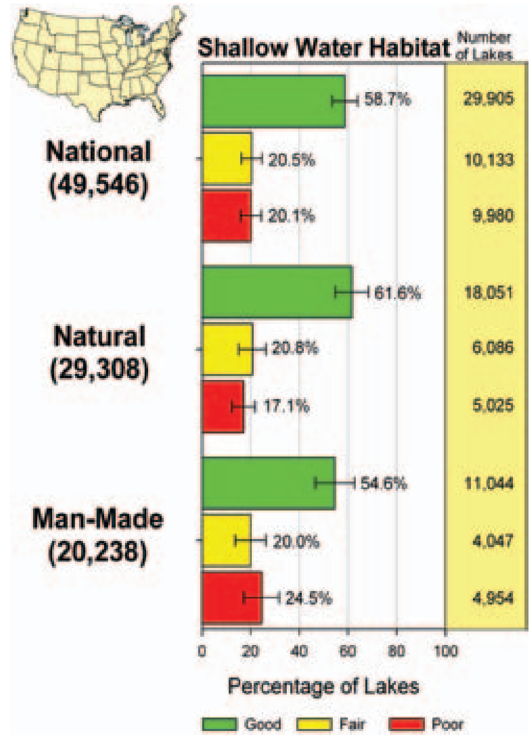


Figure 12. Shallow water habitat for lakes of the U.S. as percent of lakes in three condition classes.

Findings for Habitat Integrity

The findings for the three habitat stressor indicators are depicted in Figures 11, 12 and 13. Nationally, 46% of lakes exhibit good lakeshore habitat condition, while 18% of lakes are in fair condition and 36% are in poor condition. With respect to the shallow water areas of lakes, 59% of lakes exhibit good habitat condition, while 21% of lakes are in fair condition, and 20% are in the most disturbed, or poor condition. For physical habitat complexity of the land/water interface, 47% of lakes are in good condition, 20% of lakes are in fair condition, and 32% are in poor condition. For all three habitat indicators, more natural lakes support healthy combined habitat condition than man-made lakes.

Lakeshore Human Disturbance

In the above discussion of the lakeshore environment, the condition of lakes was described in terms of habitat integrity in both the lakeshore and shallow water areas of the lake. The fourth indicator of physical habitat is lakeshore human disturbance and reflects direct human alteration of the lakeshore itself. These disturbances can range from minor changes (such as the removal of trees to develop a picnic area) to major alterations (such as the construction of a large lakeshore residential complex complete with concrete retaining walls and artificial beaches). The effects of lakeshore development on the quality of lakes include excess sedimentation, loss of native plant growth, alteration of native plant communities, loss of habitat structure, and modifications to substrate types. These impacts, in turn, can negatively affect fish, wildlife, and other aquatic communities.

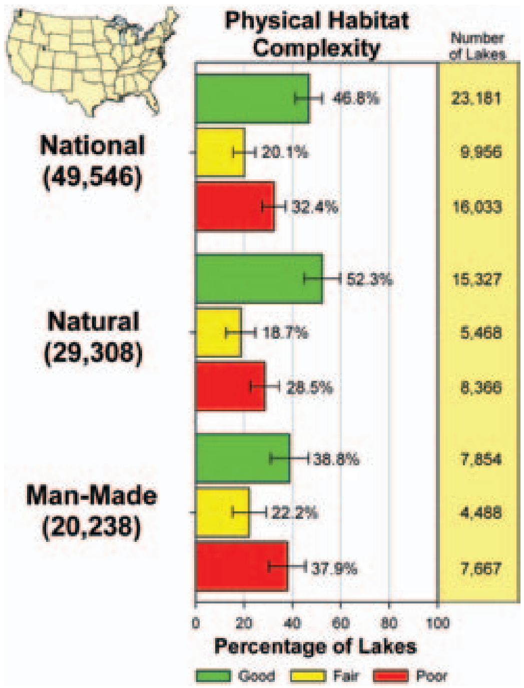


Figure 13. Physical habitat complexity for the lakes of the U.S. as percent of lakes in three condition classes.

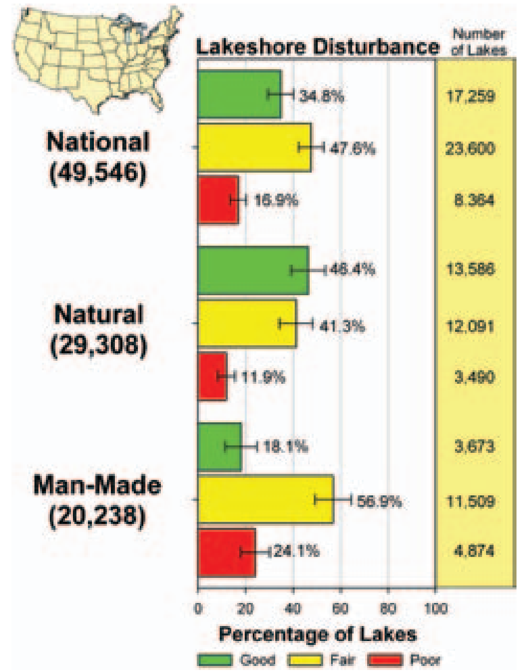


Figure 14. Lakeshore disturbance for lakes of the U.S. as percent of lakes in three conditions classes.

Findings for Lakeshore Disturbance

Across the lower 48 states, 35% of lakes exhibit good conditions representative of relatively low human disturbance levels, while 48% of lakes exhibit moderate disturbance, and 17% exhibit poor, or highly disturbed conditions (Figure 14). In contrast to the other three habitat indicators, the percentage of natural lakes that have minimal lakeshore disturbance is substantially higher than that of man-made lakes. Forty-six percent of natural lakes are in good condition compared to 18% of man-made lakes. These findings also show that there are twice as many man-made lakes with high lakeshore disturbance (poor condition) as natural lakes.

Ranking of Stressors

An important key function of the national assessments is to provide a perspective on key stressors impacting biological condition in lakes and rank them in terms of the benefits expected to be derived from reducing or eliminating these stresses. For the NLA, analysts used three approaches to rank stressors. The first looks at how extensive or widespread any particular stressor is, *e.g.*, how many lakes have excess phosphorus concentrations. The second examines the severity of the impact from an individual stressor when it is present, *e.g.*, how severe is the biological impact when excess phosphorus levels occur. Ranking ultimately requires taking both of these perspectives into consideration. The third approach is attributable risk, which is a value derived by combining the first two risk values into a single number for ranking across lakes.

Throughout this section, the stressors are assessed and reported independently and as such do not sum to 100%. Most lakes are likely to experience multiple stressors simultaneously which can result in cumulative effects rather than those elicited by a single stressor.

Relative Extent

Relative extent is a way of evaluating how widespread and common a particular stressor is among lakes. A stressor with a high relative extent indicates a significant concern. Conversely, stressors that occur over a small area (*i.e.,* hot spots) or that occur over a wide area but are spread out have a low relative extent. It is important for water resource managers to take into account the extent of the stressor when setting priority actions at the national, regional, and state scale.

Nationally, the most widespread stressors measured as part of the NLA are those that affect the shoreline and shallow water areas, which in turn can affect biological condition. Results from the NLA show that the most widespread of these is the alteration of lakeshore habitat.

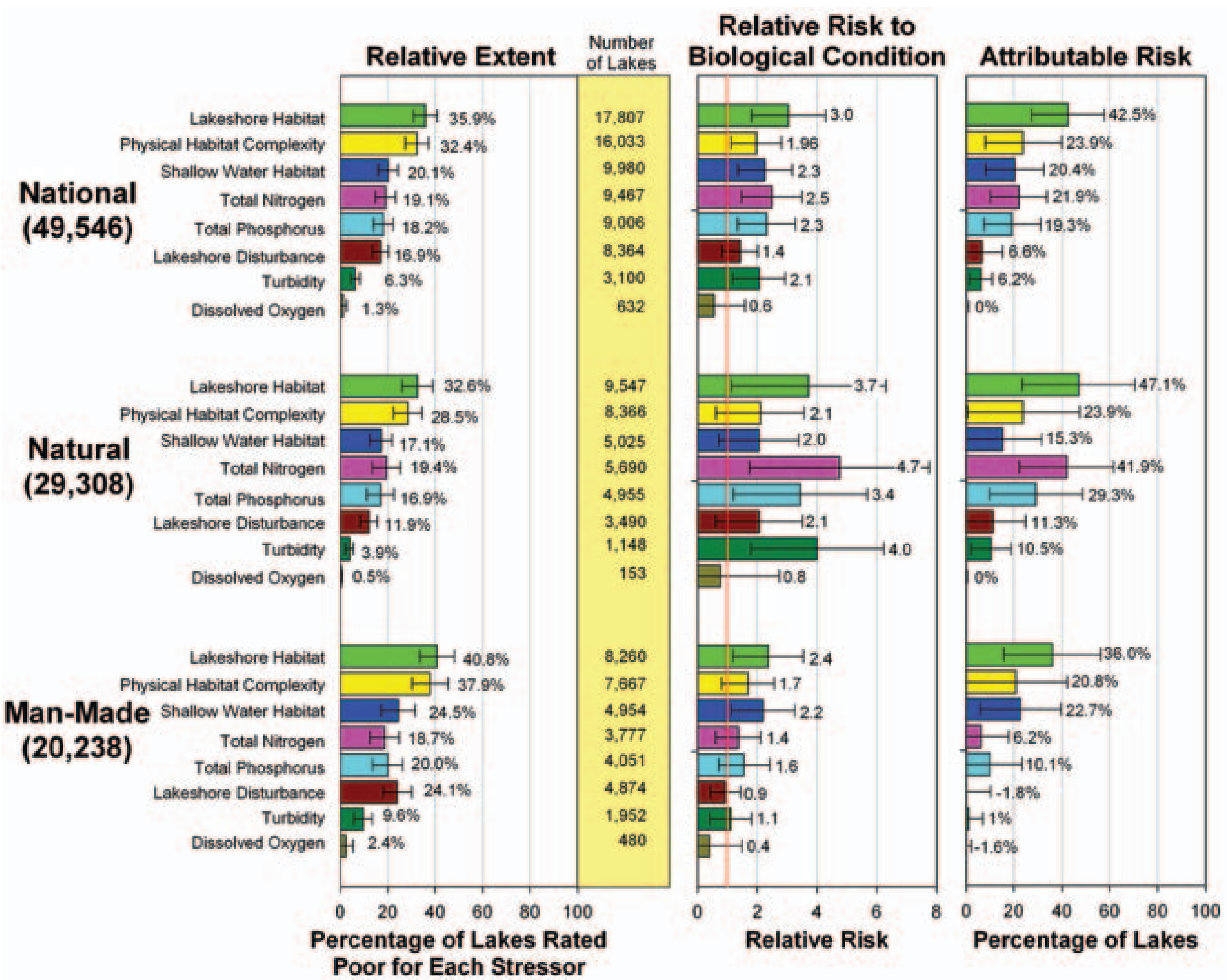


Figure 15. Relative extent of poor stressors conditions. Relative risks of impact to plankton O/E and Attributable risk (combining Relative extent and Relative risk).

Thirty-six percent of lakes nationally have poor lakeshore habitat (Figure 15, left graph). The second most prevalent stressor is physical habitat complexity, which is poor in 32% of lakes nationally. Total nitrogen and total phosphorus ranked fourth and fifth, respectively, in terms of how widespread excess levels are across the country.

The ranking of these stressors according to extent is similar across natural and man-made lakes with most stressors being more widespread in man-made lakes (*e.g.*, lakeshores with poor habitats occurring at 41% of man-made lakes compared with 33% of natural lakes).

Relative Risk

The evaluation of relative risk is a way to examine the severity of the impact of a stressor when it occurs. Relative risk is used frequently in the human health field. For example, a person who smokes is 10-20 times more likely to get and die of lung cancer[4]. Similarly, one can examine the likelihood of having poor biological conditions when phosphorus concentrations are high compared with the likelihood of poor biological conditions when phosphorus concentrations are low. When these two likelihoods are quantified, their ratio is called the relative risk. For the NLA, only the relative risk of stressor to poor conditions is presented.

Results of the relative risk analyses are presented in the middle graph of Figure 15. The highest relative risk nationally was found for lakeshore habitat disturbance with a relative risk just over 3. This means that lakes with poor surrounding vegetation are about 3 times more likely to also have poor biological conditions, as defined for this assessment. The remaining stressors, with the exception of

Survey crew member records shoreline habitat data.
Photo courtesy of Texas Commission of Environmental Quality.

dissolved oxygen and lakeshore disturbance, have relative risks near 2 (*i.e.*, twice as likely to have poor biological conditions). The relative risks for stressors in natural lakes appear consistently greater than the relative risk values for man-made lakes.

Attributable Risk

As mentioned, attributable risk is derived by combining the relative extent and the relative risk into a single number for the purposes of ranking. Conceptually, attributable risk provides an estimate of the proportion of poor biological conditions that could be reduced if poor conditions of a particular stressor were eliminated. This risk value represents the magnitude or importance of a potential stressor and one that can be ranked and prioritized for policy makers and managers.

Estimates for attributable risk based on the planktonic O/E indicator of biological condition are presented in right graph of Figure 15. Lakeshore habitat alteration has the highest attributable risk for plankton taxa loss while other stressors (with the exception of lakeshore disturbance, turbidity and

[4] Centers for Disease Control. http://www.cdc.gov/cancer/lung/risk_factors.htm

dissolved oxygen) have similar attributable risk values. Thus one might expect that to improve lake condition to the greatest extent, lakeshore vegetative habitat would have to be increased to the point that it is no longer a stressor. Natural lakes show a slightly different pattern in attributable risk with lakeshore habitat being a high priority followed closely by total nitrogen, total phosphorus and physical habitat complexity. For man-made lakes, three of the four habitat indicators rank the highest in attributable risk.

Human shoreline disturbance is an important stressor in lakes.
Photo courtesy of Great Lakes Environmental Center.

Lakeshore Alteration Stress

By Kellie Merrell, VT Department of Conservation

Transformation of lakeshores from natural forested and wetland cover to lawns and sandy beaches, accompanied by residential homes development (and redevelopment) is a stressor to many lakes. In a survey of 345 lakes in the Northeast during the early 1990s, the U.S. Environmental Protection Agency and U.S. Fish and Wildlife Service determined that stress from shoreline alteration was a more widespread problem than eutrophication and acidification. In recent years, many state agencies have documented the effects of shoreline development on nearshore and shallow water habitat quality with notable results.

As lakeshores are converted from forests to lawns, lakes are impacted by impervious surfaces, enhanced runoff, less shading, and in most cases, more abundant aquatic plant growth in shallow areas. Shallow water habitat is further simplified by the direct removal of woody structure, and interruption in the resupply of this critical habitat component. The Wisconsin Department of Natural Resources has estimated that unbuffered developed sites contribute five times more runoff, seven times more phosphorus and 18 times more sediment to a lake than the naturally forested sites.

This alteration of the nearshore and shallow water habitat affects a variety of both terrestrial and aquatic wildlife and has been described in the literature. Green frog, dragonfly, and damselfly populations decline. The nesting success and diversity of fish species also declines, with sensitive native species being replaced by more tolerant species. Turtles lose basking sites and corridors to inland nest sites. Bird composition shifts from insect-eating to seed-eating species. Even white-tailed deer are affected, with reduction in winter browse along shorelines reducing winter carrying capacity. The removal of conifers along shores also reduces shoreline mink activity. Ultimately, the cumulative effects of lakeshore development have negative implications for many species of fish and wildlife.

CHAPTER 4.
SUITABILITY FOR RECREATION

Photo courtesy of Washington Department of Ecology

IN THIS CHAPTER

Chapter 4

Suitability for Recreation

Another perspective on lake condition views the quality of a lake in terms of its suitability or safety for recreational use. Lakes are used for a wide variety of recreational opportunities that include swimming, waterskiing, windsurfing, fishing, boating, and many other activities. However, a number of microbial organisms, algal toxins, and other contaminants present in lakes can make people sick. NLA analysts assessed three indicators with respect to recreational condition: 1) microcystin – a type of algal toxin, 2) cyanobacteria – a type of algae that often produces algal toxins, and 3) chlorophyll-*a* — a measure of all algae present. Results from a companion study of contaminants in fish tissue are also discussed. Samples were also collected for pathogens and sediment mercury; however, results for these two indicators are unavailable as of publication of this report and will be presented in a supplemental report available on http://www.epa.gov/lakessurvey/.

Algal Toxins

One group of phytoplankton, cyanobacteria, (also called blue-green algae) are a natural part of all freshwater ecosystems. Eutrophication in lakes often results in conditions that favor their growth and cyanobacterial blooms frequently occur. Cyanobacterial blooms can be unsightly, often floating in a layer of decaying, odiferous, gelatinous scum. Many types of cyanobacteria have the potential to produce cyanotoxins, and several different cyanotoxins may be produced simultaneously. In assessing the risk of exposure to algal toxins for recreational safety, it is important to remember that algal density, *i.e.*, chlorophyll-*a* concentrations and cyanobacteria cell counts, serve as proxies for the actual presence of algal toxins. This is because not all phytoplankton are cyanobacteria and not all cyanobacteria produce cyanotoxins.

Although there are relatively few documented cases of severe human health effects, exposure to cyanobacteria or their toxins may produce allergic reactions such as skin rashes, eye irritations, respiratory symptoms, and in some cases gastroenteritis, liver and kidney failure, or death. The most likely exposure route for humans is through accidental ingestion or inhalation during recreational activities, though cyanotoxins are also cause for concern in drinking water. Cyanotoxins can also kill livestock and pets that drink affected water. While many varieties of cyanotoxin exist, microcystin, produced by *Microcystis* taxa, is currently believed to be the most common in lakes. Microcystin is a potent liver toxin, a known tumor promoter, and a possible human carcinogen.

Table 1. World Health Organization thresholds of risk associated with potential exposure to cyanotoxins.

Indicator (units)	Low Risk of Exposure	Moderate Risk of Exposure	High Risk of Exposure
Chlorophyll-*a* (µg/L)	<10	10 - <50	>50
Cyanobacteria cell counts (#/L)	< 20,000	20,000 - <100,000	≥ 100,000
Microcystin (µg/L)	<10	10 - ≤20	>20

Because of the potential for human illness, several states have issued guidelines for recreational use advisories associated with the presence of microcystin or associated indicators. These guidelines vary and rely on visual observations of algal scums, measured chlorophyll-*a* concentrations, cyanobacteria cell counts, and/or direct measurements of microcystin. While EPA does not presently have water quality criteria for microcystin, cyanotoxin, or any other algal toxins, the World Health Organization (WHO) has established recreational exposure guidelines for chlorophyll-*a*, cyanobacterial cell counts, and microcystin (Table 1).

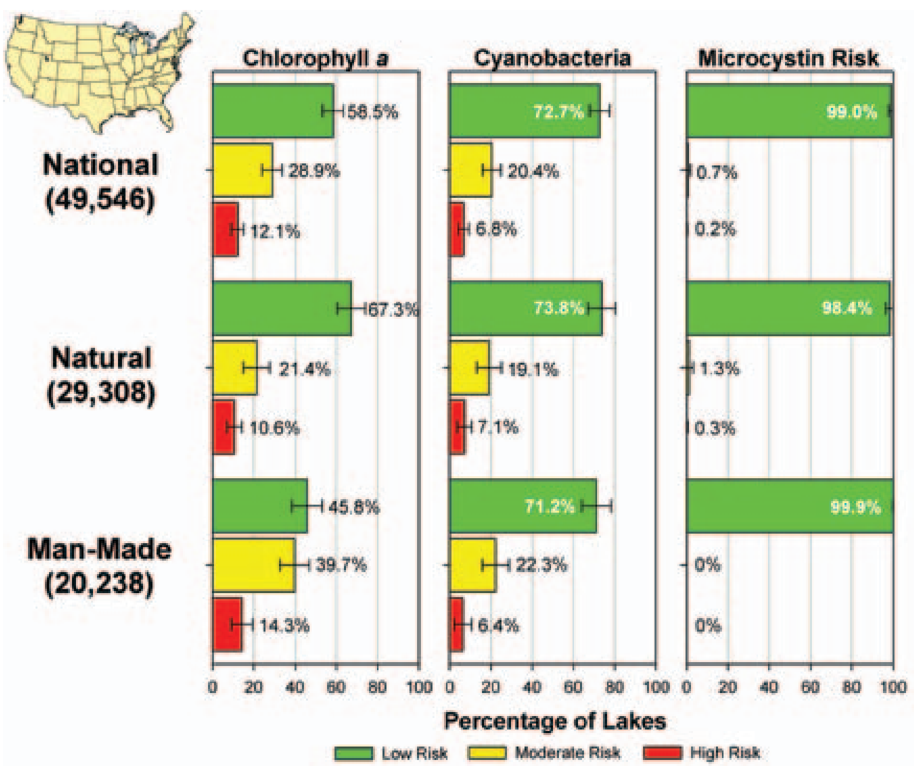


Figure 16. Percent of lakes, using three algal toxin indicators. In the first two graphs the percentage numbers indicate the risk or exposure to algal toxins associated with the presence of chlorophyll-*a* and cyanobacteria, not the risk of exposure to cholorphyll-*a* and cyanobacteria *per se*.

These thresholds, along with the presence or absence of microcystin, were used to assess the condition of lakes of the nation with respect to this indicator suite. A lake that is in good condition exhibits a low risk of potential exposure. Conversely, a lake in poor condition has a high exposure potential.

Using the WHO thresholds, the level of risk associated with the exposure to algal toxins varied and by indicator (Figure 16). Using the cyanobacteria cell count as the indicator, 27% of lakes nationwide pose a high or moderate risk for potential exposure to algal toxins. There was no significant difference in the proportion of natural and man-made lakes with high or moderate exposure risks for cyanobacteria. Based on chlorophyll-*a* concentration, 41% of lakes pose a high or moderate exposure potential to algal toxins.

It is important to note, however, that while the risk of exposure is extremely low, microcystin was present in 30% of lakes nationally (Figure 17). This could potentially have wide ranging impacts on human health and the swimmability of many lakes. When interpreting the data of this first ever national-scale study of microcystin in lakes, it is necessary to consider how the sampling was conducted. During the 2007 survey, microcystin samples were collected at mid-lake, in open water. However, large windblown accumulations of cyanobacteria often occur at nearshore areas in lakes and it is the concentrations along the lake's edge that are of most concern to municipal health officials. Some studies indicate that cell counts and cyanotoxin concentrations are greater in nearshore scums than in open water areas. However, concentrations large enough to cause human health concerns may still occur in open waters (with or without surface accumulations or scums). Sampling at mid-lake provides a conservative estimate

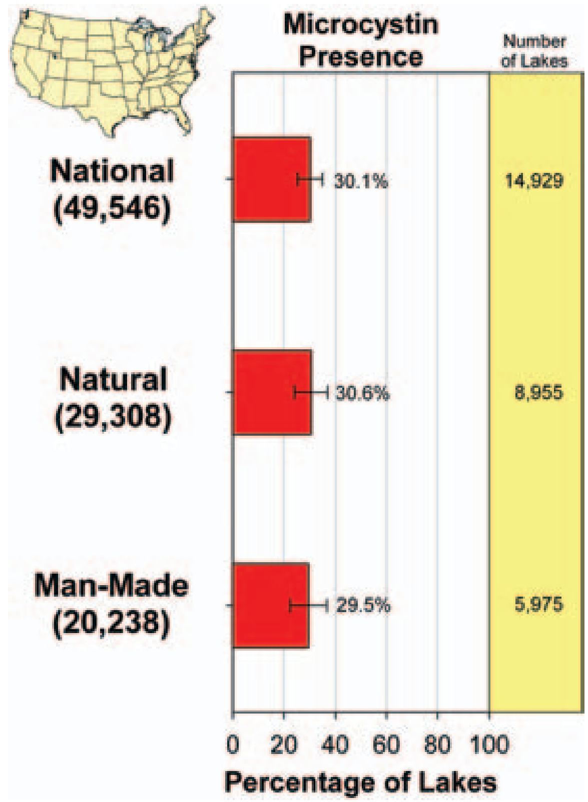


Figure 17. Occurrence of microcystin in lakes.

and because of this, the NLA results may underestimate certain types of recreational exposure when accumulations or scums are present.

Another important point to consider when looking at the data is whether the single sample of microcystin truly represents what is in the lake. Chlorophyll-*a* levels, cyanobacteria densities, and cyanotoxin concentrations may change quite rapidly, depending on bloom intensity and weather conditions. The concentrations of microcystin measured on one particular day may over or underestimate season-wide central tendencies. The NLA is not intended to assess the specific condition of any given lake, but rather provide information on the general conditions across the population of lakes. Finally, it is currently unknown how well microcystin occurrence correlates with the occurrence of other classes of cyanotoxins that were not measured, or how human health risks might be altered because of toxin mixtures. While the survey results are a good start in our understanding, much more is to be learned about algal toxins in lakes.

Contaminants in Lake Fish Tissue

Fish acquire contaminants and concentrate them in their tissues by uptake from water (bioconcentration) and through ingestion (bioaccumulation). Fish can often bioaccumulate chemicals at levels of more than a million times the concentration detected in the water column.

In a study conducted by the Office of Water's Office of Science and Technology, EPA surveyed contaminants in lake fish tissue. *The National Study of Chemical Residues in Lake Fish Tissue* characterized contaminant levels in fillet tissue for predators and in whole bodies for bottom-dwelling fish species. The study targeted pollutants that were classified as persistent, bioaccumulative, and toxic (PBT) chemicals, including mercury, arsenic, PCBs, dioxins and furans, DDT, and chlordane. This survey provided data to develop national estimates for 268 PBT chemicals in fish tissue from lakes and reservoirs in the 48 continental states (excluding the Great Lakes and the Great Salt Lake).

The study focused on fish species that are commonly consumed in the study area, have a wide geographic distribution, and potentially accumulate high concentrations of PBT chemicals. Fish samples were collected over a 4-year period (2000-2003) from 500 randomly selected lakes and reservoirs, which ranged in size from 2.5 acres (1 hectare) to 900,000 (365,000 hectares), were at least 3 feet (1 meter) deep, and had permanent fish populations.

The data show that mercury, PCBs, dioxins and furans, and DDT are widely distributed in lakes and reservoirs across the country. Mercury and PCBs were detected in all fish samples (Figure 18). Dioxins and furans were detected in 81% of the predator samples and 99% of the bottom-dwelling fish samples. DDT was detected in 78% of the predator samples and 98% of the bottom-dwelling samples. Cumulative frequency distribution plots showed that established human consumption limits were exceeded in 49% of the sampled lakes for mercury, in 17% of the lakes for total PCBs, and in 8% of the lakes for dioxins and furans. In contrast, 43 targeted chemicals were not detected in any sample. Full results from this study can be found at http://www.epa.gov/waterscience/fishstudy.

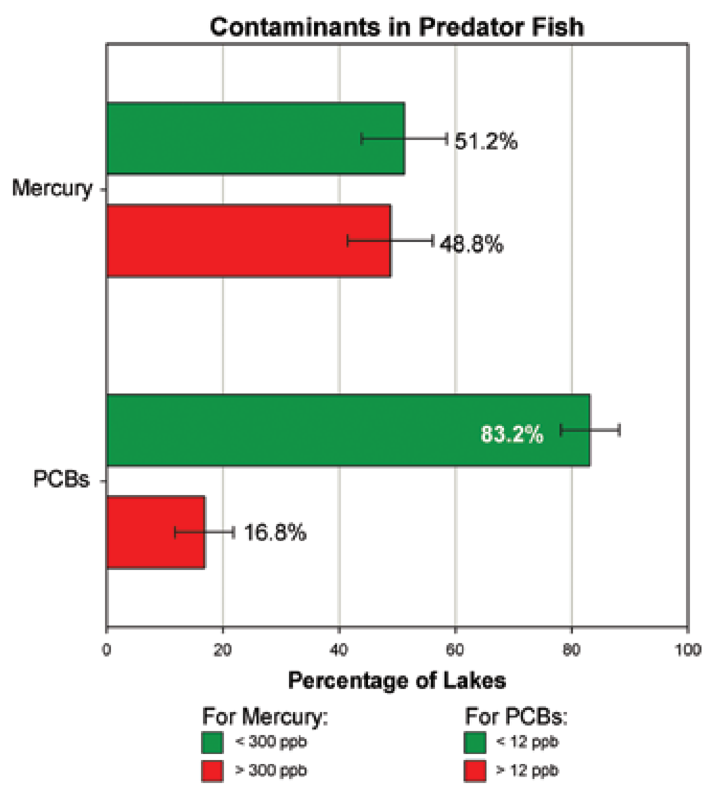


Figure 18. Percentage predator fish with mercury and PCB levels above (red) and below (green) EPA recommended limits.

Pathogen Indicators

Enterococci are believed to provide a better indication of the presence of pathogens than more traditional indicators for fecal coliform. *Enterococci* are bacteria that live in the intestinal tracts of warm-blooded creatures, including humans.

They are most frequently found in soil, vegetation, and surface water because of contamination by animal excrement. Most species of *enterococci* are not considered harmful to humans. However, the presence of *enterococci* in the environment indicates the possibility that other disease-causing agents also carried by fecal material may be present. Epidemiological studies of marine and freshwater beaches have established a relationship between the density of *enterococci* in the water and the occurrence of gastroenteritis in swimmers.

For the NLA, *enterococci* were measured using a method to assess ambient concentrations. This Quantitative Polymerase Chain Reaction (qPCR) method quantifies DNA that is specific to *enterococci*. Published epidemiological studies report a clear relationship between levels of qPCR-measured *enterococci* and sickness. EPA research is still underway to develop health-based thresholds for interpreting qPCR results.

Analyzing phytoplankton samples.
Photo courtesy of EcoAnalysts.

HIGHLIGHT

Atmospheric Contaminants: Mercury and Acid Rain

Neil C. Kamman
Vermont Department of Environmental Conservation

Of the many stressors that affect lakes, atmospheric contaminants are perhaps the most difficult to address. This is because sources of atmospheric contaminants are often hundreds or even thousands of miles from the lakes into which the contaminants are ultimately deposited. The intertwined issues of freshwater acidification and mercury contamination are not new. The popular press began reporting on acid rain in the 1970s. It took another 10-15 years for the press to also focus on mercury. Today, many people are aware of both issues, yet often do not fully comprehend nor appreciate the degree to which the two are linked. In the case of both these pollutants, the cycle is initiated by emissions into the air.

Mercury is a naturally occurring metal that is found in the environment in many forms, all of which are toxic to aquatic life in varying degrees. The release of mercury to the environment is enhanced by human activities such as the combustion of fossil fuels, such as coal and petroleum. In the U.S. the largest sources of mercury are coal-fired generation or utility boilers, followed by waste incinerators. Mercury is present in many household items, notably thermostats and fluorescent lamps, and is released when these items end up in landfills or incineration facilities. Depending on its chemical form, air-borne mercury may remain in the atmosphere for a period of minutes (as reactive gaseous mercury), days (as particulate mercury), or weeks or years (as gaseous elemental mercury).

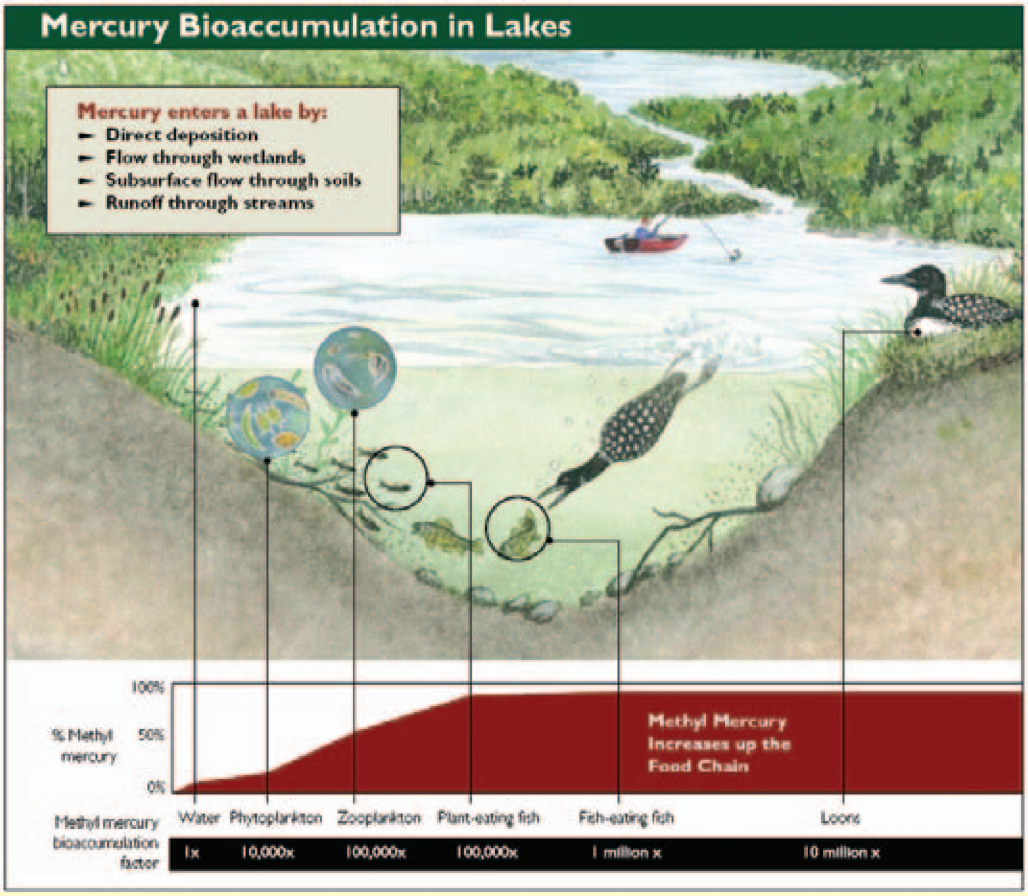
Methylmercury, one of the most toxic forms of mercury, can be prevalent in fish and has documented adverse health effects on humans. The U.S. Centers for Disease Control and Prevention estimates that up to 6% of women of childbearing age have blood mercury levels in excess of established safety levels. Fish and fish-eating wildlife such as the common loon and American bald eagle are also at risk from mercury toxicity. While the mercury cycle in lakes is quite complex, there are five basic stages: emission, deposition, methylation*, bioaccumulation, and finally sequestration to lake sediments.

Lake acidification is most commonly caused by acidic deposition (rain, snow and dust). The acidic deposition pathway begins with the release into the air of acid-forming chemicals, most notoriously sulfur dioxide and nitrogen oxides, and ends when sulfuric and nitric acids are deposited to the landscape. Sulfur dioxide, like mercury, results largely from the burning of fossil fuels. Some forms of coal are very rich in sulfur, and poorly controlled facilities released massive quantities, particularly during the period 1960-1992. Both sulfur dioxide and nitrogen oxides are common components of vehicular emissions. Once emitted, these two compounds undergo complex atmospheric transformations, resulting in rain and snow that contain dilute concentrations of nitric and sulfuric acids. Thankfully, the Clean Air Act Amendments of 1990 have resulted in profound reductions in acid-forming precursors. In very sensitive regions, however, lakes remain at risk for acidification even with reduced levels of acid rain.

In one sense, the process of lake acidification is not as complex as that of mercury accumulation in that there is neither methylation nor bioaccumulation of the acids. Yet acidification has more pernicious effects that can exacerbate mercury problems. Acidification of watersheds renders the watersheds more efficient at creating and transporting methylmercury to lakes, along with other soil-bound toxic metals such as aluminium. Moreover, acidification of the lakes themselves renders the bioaccumulation of methylmercury more efficient. Therefore, acidic lakes: 1) receive more mercury from their watershed, 2) have more of the mercury in the toxic methylated form, and 3) have more efficient bioaccumulation of the methylmercury.

*The natural and biologically-mediated process by which mercury is transformed into toxic organic methylmercury.

Studies throughout the United States, Canada, Russia, and Scandinavia all show a very strong connection between lake acidification and mercury bioaccumulation. Researchers have documented the occurrence of mercury hotspots in various parts of the U.S. and attribute these to one of three basic causes — proximity to poorly-controlled emissions sources, water level management in reservoirs, or acid sensitive landscapes. In regions of North America where lake acidification is in fact already improving, minor reductions in mercury in fish and fish-eating wildlife can be anticipated. Much more consequential reductions in environmental mercury contamination are expected as EPA and states strive to control mercury emissions from coal-fired utilities and other sources.



Graphical depiction of methylmercury bioaccumulation in lake biota. This figure is reproduced from the Hubbard Brook Research Foundation's ScienceLinks publication Mercury Matters: Linking Mercury Science with Public Policy in the Northeastern United States. Used with permission.

CHAPTER 5. TROPHIC STATE OF LAKES

Photo courtesy of USEPA Region 10

IN THIS CHAPTER

► Findings for Trophic State

Photo courtesy of Great Lakes Environmental Center

Chapter 5
Trophic State of Lakes

The third approach to assessing the condition of lakes is to look at lakes with respect to their primary production. Trophic state depicts biological productivity in lakes. Lakes with high nutrient levels, high plant production rates, and an abundance of plant life are termed eutrophic, whereas lakes that have low concentrations of nutrients, low rates of productivity and generally low biomass are termed oligotrophic. Lakes that fall in between are mesotrophic, and those on the extreme ends of the scale are termed hypereutrophic or ultra-oligotrophic. Lakes exist across all trophic categories; however hypereutrophic lakes are usually the result of excessive human activity and can be an indicator of stress conditions.

There is no ideal trophic state for lakes as a whole since lakes naturally fall in all of these categories. Additionally, the determination of "ideal" trophic state depends on how the lake is used or managed. For example, an oligotrophic lake is a better source of drinking water than a eutrophic lake because the water is easier or less expensive to treat. Swimmers and recreational users also prefer oligotrophic lakes because of their clarity and aesthetic quality. Eutrophic lakes can be biologically diverse with abundant fish, plants, and wildlife. For anglers, increased concentrations of nutrients, algae, or aquatic plant life generally result in higher fish production.

Eutrophication is a slow, natural part of lake aging, but today human influences are significantly increasing the amount of nutrients entering lakes. Human activities such as poorly managed agriculture or suburbanization of lakeshores can result in excessive nutrient concentrations reaching lakes. This can lead to accelerated eutrophication and related undesirable effects including nuisance algae, excessive plant growth, murky water, odor, and fish kills.

Findings for Trophic State

For NLA, the trophic state is characterized using nationally-consistent chlorophyll-*a* concentrations (Figure 19). Based on these thresholds, 13% of lakes are oligotrophic, 37% are mesotrophic, 30% are eutrophic, and 20% are hypereutrophic. The results also show that natural lakes tend towards mesotrophic conditions and man-made lakes towards eutrophic conditions.

Many states and lake associations classify their lakes by trophic state using a variety of thresholds for nutrients (phosphorus or nitrogen), Secchi disk transparency, or chlorophyll-*a*, depending on the data available. For this assessment, NLA analysts, in consultation with a number of state and local lake experts, decided to base trophic state on chlorophyll-*a* concentrations. The group considered this indicator the most relevant and straightforward estimate of trophic state because it is based on direct measurements of live organisms, yet acknowledges that other indicators also could be used. Table 2 illustrates the percentages that would fall into the different trophic categories if different indicators were used. Total nitrogen and total phosphorus, (which ranked fourth and fifth in terms of how widespread excess levels are across the country) together or individually are primary drivers of eutrophication.

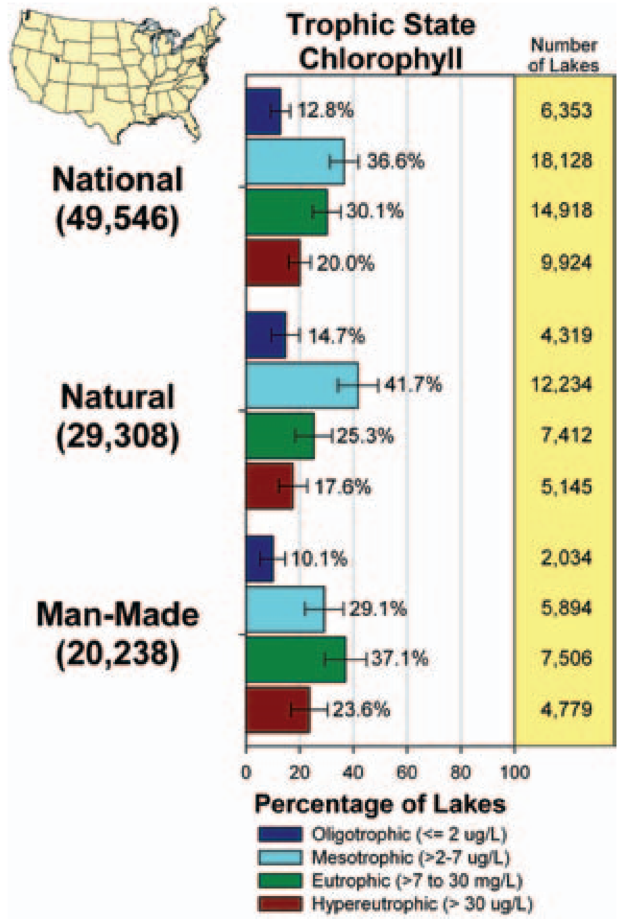


Figure 19. Trophic state of lakes in the lower continental U.S.

Table 2. Percent of U.S. lakes (natural and man-made) by trophic state, based on four alternative trophic state indicators.

Indicator	Oligotrophic	Mesotrophic	Eutrophic	Hypereutrophic
Chlorophyll-*a*	12.8	36.6	30.1	20
Secchi transparency	10.5	22.5	39.8	18.4
Total Nitrogen	22.1	37.5	22.0	18.4
Total Phosphorus	25.0	28.8	24.7	21.4